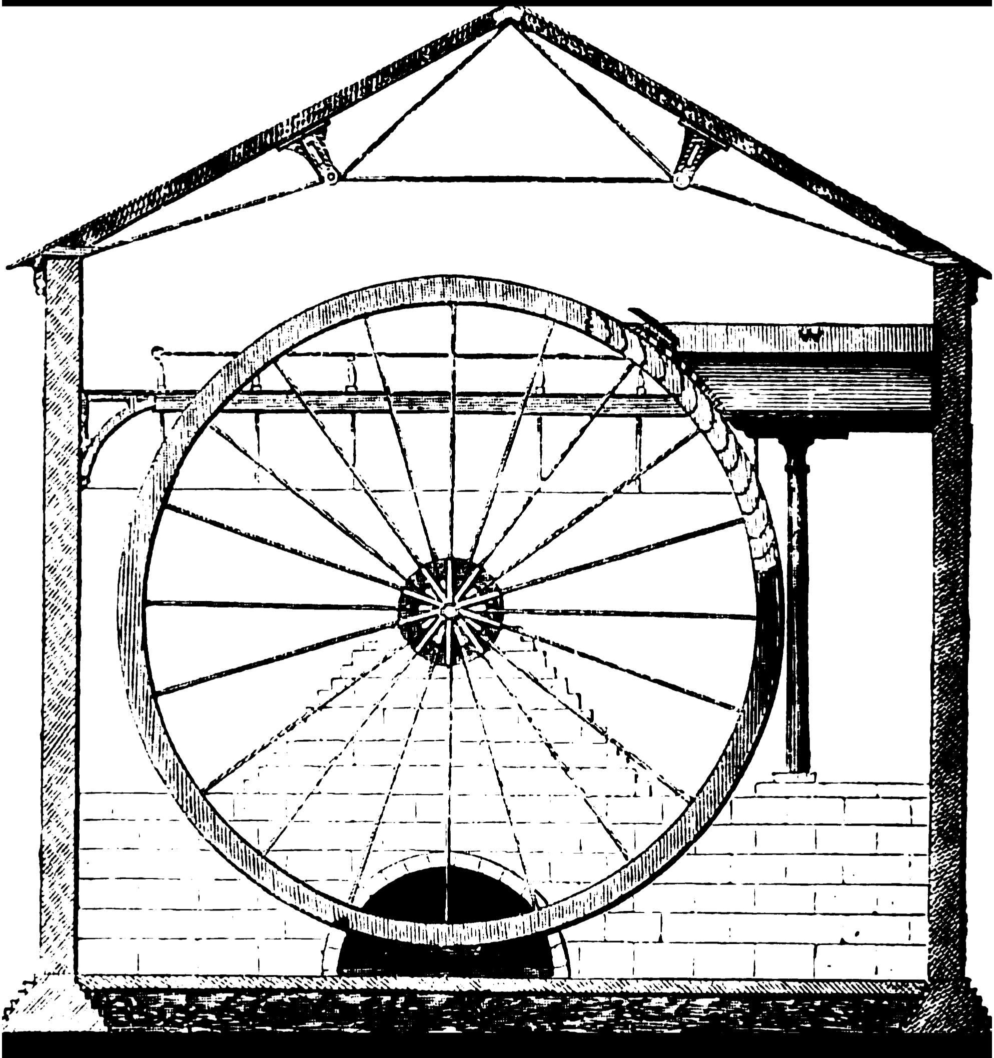

The useful metals and their alloys

John Scoffern

THE USEFUL METALS

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AND

THEIR ALLOYS.

THE USEFUL METALS

AND THEIR ALLOYS

INCLUDING

MINING VENTILATION, MINING JURISPRUDENCE, AND METALLURGIC CHEMISTRY

EMPLOYED IN THE CONVERSION OF

IRON, COPPER, TIN, ZINC, ANTIMONY, AND LEAD ORES;

WITH THEIR APPLICATIONS TO

THE INDUSTRIAL ARTS.

BY

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PREFACE

THE term USEFUL METALS is applied in the present volume to distinguish it from the noble or PRECIOUS METALS; it also indicates with sufficient exactness, the metals applicable to ordinary industrial purposes, embracing Iron, Copper, Tin, Zinc, Antimony, Lead, and their various alloys. In treating of these metals and the chemical principles which influence their conversion, the Editor has been fortunate enough to obtain the assistance of writers qualified from their connection with Metallurgic Science, and with practical working in metals, to do ample justice to their respective subjects.

In order that these gentlemen may be responsible only for their own statements, and that the reader may have sufficient authority for the several processes and principles described and explained, a few remarks are here necessary.

For the Chapters on Metallurgic Chemistry and Assaying, the Editor is indebted to Dr. Scoffern, who has furnished the first four chapters of the work, and for these only is he responsible.

The Chapters on Mining, Mining Ventilation, and Jurisprudence, were written for the work by a Government Inspector of mines. The space reserved for these chapters was necessarily very limited and the subjects treated with brevity; but brief as they are, it is believed that if the rules here laid down, were more rigorously adopted in coal and other mines, such catastrophes as we have lately had occasion to deplore, would become all but impossible.

The Chapters on Iron and the several processes used in its Conversion, have been prepared by Mr. Truran, C.E., author of the "History of British Iron Manufacture," and for many years engineer at the Dowlais, Hirwain, and Forest Iron Works under Sir John Guest, and Mr. Crawshay. It is necessary to add here that, Mr. Truran is not answerable for the papers on the recently patented processes described in Chapter XIV, nor for the opinions expressed respecting them.

In describing the manipulative processes, we are indebted to Mr. Clay of the Mersey Iron and Steel Works, for the processes and tools necessary for working Malleable Iron in large masses, including the details connected with the large Wrought-Iron gun presented to the Nation by that Company, of which Mr. Clay is the Manager.

For the paper on Steel manufacture, the Editor is indebted to a gentleman of great practical experience, who wishes to remain unknown. It is but justice, however, to this gentleman, to state that he is neither responsible for the opinions expressed respecting Heath's and other patented processes named; nor for the statements respecting Mr. Huntsman's discovery of Cast-Steel, these details having been communicated through another channel.

The application of Iron to the purposes of Ordnance, Machinery, Bridges, and to House and Ship building, by Wm. Fairbairn, F.R.S., will be read with interest; Mr. Vose Pickett's summary of his New System of Iron Architecture, is also a subject to which public attention is not unlikely to be more particularly directed.

The Chapters on Iron working for Use and Ornament, and the Manipulation and Construction of Ornamental Iron-work, by Mr. W. C. Aitkin, of the Cambridge Works, Birmingham, will be found worthy of the attention of the practical reader.

The Chapters on Copper, Tin, Zinc, and Antimony, are by Mr. Oxland of Plymouth, with the exception of the portions on Copper and Tin Mining, which are partly by Mr. Truran, and partly by Mr. Oxland.

It was intended that this volume should conclude with a paper on Lead from the pen of Dr. Richardson; but at his suggestion it has been determined to postpone this paper; the intention now being that Dr. Richardson in connection with Mr. Sopwith, C.E., manager of the Allenhead Lead Works, should prepare a complete and comprehensive treatise on the subject, embracing all the modern inventions connected with this important metal, and treating of it in connection with silver, with which it is so constantly found in nature. The short treatise now given, therefore, is a compilation for which Dr. Richardson is in no respect responsible, and is only added in order that so important a metal should not seem to be overlooked in a volume treating of the "Useful Metals."

AMEN CORNER, PATERNOSTER ROW,
July, 1857.

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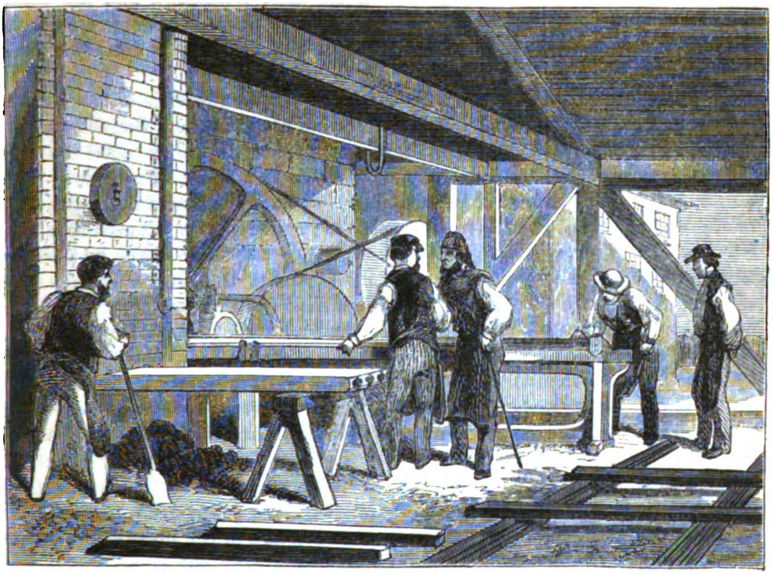
THE USEFUL METALS AND THEIR ALLOYS.



THE USEFUL METALS AND THEIR ALLOYS.

CHAPTER I.

ON METALLURGIC CHEMISTRY.

In adopting the title "useful metals" as a basis of classification, a casual survey of the materials concerned is alone necessary to render evident the conventional nature of the term. To affirm that all the metals are useful, is only to narrow the universal proposition that everything which God has made is useful: various evident degrees of utility, however, there are in all created things; and especially does this remark apply to metals. We anticipate, therefore, but little difficulty in effecting a division of this subject.

In every treatise of technical import, some kind of practical classification is involved; and in a matter of such universal interest as the metals, it appeared to the editors of this volume that monographs on the "*useful*" metals, dealt with by practical men, would come before the world with significance enough to command attention in this pre-eminently metallic age.

By no means, however, is it to be supposed that we regard the metals excluded from this class as useless. On the contrary, we hope to deal with them hereafter in a way that shall vindicate the division we have adopted;

while we exercise the same supervision on their treatment, and the same conscientiousness of selection, as to authorship, which have been brought to bear on the production of the monographs about to be submitted to public notice.

The principles which have been adopted for the guidance of the editors should be here explained. They are somewhat peculiar; and therefore somewhat novel. Social circumstances have worked amongst other social changes a division of persons into those who write books and those who do not. Certain facilities of acquaintance with the heads of a subject, and a corresponding readiness in turning it into presentable shape, have been adopted as a profession. The art has been cultivated of putting facts into shape by persons often ignorant of the significance and ramifications of those facts; thus constituting the art of book-making as distinguished from the art of fact-teaching by books. It appeared to us, that the art had been carried too far for the interests of true scientific instruction—that a store far too great had been set upon the blandishments of literary style in matters purely utilitarian, and that if choice there needs must exist, between a truth inelegantly told by a practical man who knew the import of that truth, and who told it whilst yet under the force of its inspiration, and of another who, without any practical acquaintance, could urge no better claim to appreciation than mere literary style, the former alternative should be chosen. We determined, therefore, to have nothing to do with any but practical men; and in the preparation of the forthcoming pages that determination has been worked out.

It is but just to mention these peculiarities in the system on which the present volume has been initiated. A perusal of the monographs now before us justifies the impressions under which that attempt was made; and the names of the authors pledged to the remaining papers will doubtless extend the justification.

The Useful Metals and Metallic Ores Defined.—Of sixty-four simple or elementary material bodies, no less than fifty or fifty-one are metallic. We shall not enter upon the characteristics which serve to define a metal—that more especially belongs to the functions of a chemical treatise, and has already been done in our volume on Chemistry, in the CIRCLE OF THE SCIENCES; but taking it for granted that the attributes of a metal are sufficiently well agreed upon for popular use, we shall proceed to offer a few general remarks on their useful properties, of which rigidity, cohesion, tenacity, and durability, are the most remarkable, although many more are conjoined in variable degrees.

The ancients were only acquainted with seven metals, whereas we know of fifty or fifty-one; nevertheless those now in most general requisition, and to which the appellation "useful metals" most peculiarly belongs, were all known to the ancients. Methods of working them, however, and new sources from which to obtain them, have multiplied so much in modern times, as almost to rank in importance with the discovery of the existence of a new metal.

Metals are either found native—that is to say, in the condition of obvious

metallic existence—or they are combined with other substances, so as to lose all obvious evidence of their metallic constitution. The latter condition is by far the more frequent; and to this fact, more than any other, the consecutive history of special metallic discovery is attributable. This circumstance leads us to an important chemical consideration, having reference to the comparative tendencies of different metals to combine with the non-metallic elements, and to lose by such combination their obvious metallic form. The term "noble metals," though applied to gold and silver in ages when the principles of chemical science were unknown, have nevertheless a positive chemical significance. Modern discovery has added platinum to the list; and they all agree in the property of being very slow to combine with any foreign material save other metals. Hence it is that they are so frequently found (gold and platinum almost universally) in the native or metallic state—united frequently with other metals, it is true, but still exhibiting the metallic aspect. If the noble metals existed in larger quantity—offered equal facility for working them, and equal hardness after being worked—their slowness to unite with oxygen would render them, more than all others, deserving of the appellation of "useful metals;" but, being deficient in these qualities, notwithstanding their nobility, they must yield the palm to iron, tin, copper, zinc, and lead, in the first instance, and perhaps to mercury, or quicksilver, and bismuth also; considering the various applications of these metals to the useful arts of life.

The progress of metallurgy and of smelting operations, demonstrates how great may be the advance of arts based upon scientific principles, without these principles being understood. The production, and utilization of metals, are intimately allied with chemistry; and deriving such immense advantages from the application of chemical principles at this time, it is extraordinary to reflect on the comparative excellence to which the art of working several useful metals had arrived, before the aggregation of chemical facts and principles to which the denomination "science" is alone justly due, had dawned. Chemical science may be indeed said to rest on an historical basis of metallurgic aspirations, and metallurgic empiricism.

Coeval with the earliest historical records, some metals were worked, and the operations of working involved the influence of chemical laws; yet the simplest principles of chemistry had not then dawned. At later periods it was alchemy—the vague hallucination of making gold—which prompted men to undertake investigations fruitful of chemical deductions, to be marshalled into a science hereafter. Metallurgy, then, may justly lay claim to be considered the fountain source of chemistry; and the subsequent development of the science to the art, might supply the theme of argument in favour of empiricism over intellectualism, if, at various periods within the last two hundred years, the miner and the metallurgist, by their devotion to chemistry, and the chemist by his successful labours in the practical fields of mining and smelting, had not demonstrated how mutual is the relation between theory and practice—how inseparable for good—how redundant of advantages the one to the other. Metallurgy (accepting the word in its most extensive signification) derives its best processes, and not unfrequently its

best practical aids, from a due appreciation of chemical principles. And, on the other hand, the mere theoretical chemist derives a useful lesson of the necessity of checking his theoretical deductions by facts, as they are found to be, by attending to some of the teachings of metallurgy. Several metallic operations there are, the success of which is at variance with all the theoretical indications of chemistry. "*Corpora non agunt nisi fluida*" was a chemical dictum of received universality; nevertheless, the practice of annealing, or the conversion of iron into steel by combination with carbon, is a practical refutation of the universality. This process consists in the heating together iron bars and wood-charcoal in a suitable furnace. Both iron and carbon are here brought together in the solid state; both may be said to be devoid of volatility—and almost of liquidity; nevertheless, in violation of the formerly received canon, combination ensues, and steel is made. A similar disaccordance between the indications of theory, and the teachings of practice, is illustrated by the hot-blast operation, introduced some years ago in the practice of iron smelting. On the other hand, chemistry illuminates many dark recesses in the field of metallic empiricism, and points to facts, the existence of which would not have been suspected.

It is unnecessary, however, further to expatiate on the advantages which the metal-worker derives from the knowledge and application of chemical theory—the connection being now admitted by none more readily than by the practical metallurgist.

Metallurgy of Antiquity.—In illustration of the mutual dependences of a branch of practical metallurgy and chemical science, it may be here not unadvisable to anticipate the contents of the monographs which especially deal with special metals, and to trace cursorily the various phases which the production of the metal iron has undergone. From one of several metalliferous sources this useful body has been produced from, perhaps, the earliest historical periods. True though it be that the ancient Greeks at the very earliest period of their history do not seem to have been acquainted with the existence of, far less the method of working, iron—yet we read of both in Scripture: and there is good reason to believe that anterior to the earliest historical record of the Greeks, iron, and the processes of manufacturing it, were known in China, and Hindostan. We know, too, that immutability is impressed on all the processes of the East; whence it is not unreasonable to infer that the processes of rude iron manufacture now followed in Asia are types of, if not identical with, the processes followed there in times long passed. What are these processes? What is their general characteristic? What are the principles involved? What is the result? One general scheme of appliances pervades them all. The object is to begin with an ore of iron capable of reduction by charcoal fuel, and of yielding a semi-fluid result, which the subsequent process of welding fashions into shape. Even in this simple form of iron-smelting a good deal of latent chemistry is involved; but the fullest acquaintance with chemistry could not improve the practice of iron-smelting as followed by the Persians and Hindoos, if limited to the means at their command, and the ends proposed to be gained. The iron manufac-

ture of England, as prosecuted in bloomaries by the aid of charcoal fuel, was only a modification of the Persian method, and conducted almost as empirically. No sooner was the practice of iron-smelting by charcoal fuel abolished, and pit-coal, or its immediate derivative coke, introduced, than an application of chemical principles became necessary. How far these applications resulted in empirical tentative experiments, or in the suggestions of chemical teaching, it would not be possible at this time to decide; but the historian of the iron manufacture has not to pursue his labours much further before the reaction of chemical knowledge on mere empiricism is made evident. Practice demonstrated the fact that coal-smelted iron was inferior to charcoal-smelted iron; but practice could not say wherefore until science came to the iron-smelter's aid; making known to him the composition of pit-coal, proving that it contained many foreign substances, which found their way into the smelted iron and injured its quality. Analysis of coal-smelted iron demonstrated the existence of both sulphur and phosphorus incorporated with it—demonstrated moreover that, *cæteris paribus*, the amount of deterioration of the iron was in direct proportion to the quantity of these elements which it contained.

Chemistry next began to shed a light on the nature and property of fluxes, in showing how a mixture of several iron ores might conduce to yield a more fluid mass in the furnace than any one ore by itself. The next chemical glimmering fell on the apprehension of Cort, that Nestor of the British iron-trade; and led to his improvements in the processes of refining and puddling, the results of which, combined with the rolling aid devised by his mechanical genius, eventuated in Britain supplying iron in large quantities to other countries from which she had heretofore obtained that metal.

Source of British Iron.—It was our proposition, that as the operations of metallurgy (accepting the word in its largest sense) came down to our own times, the reaction of theoretical chemistry upon its practical development has continued to increase. We now come to deal with the sources of British iron, which may be roughly divided into iron ores, and clay iron-stone. The former exists in various parts of these Isles; but the latter assumes an enormous bulk in certain coal-yielding localities. Whilst the supply of British wood-charcoal lasted, and before the demand for iron became so enormous, as it has from the beginning of the last century, charcoal answered its purpose tolerably well. The iron manufactured by it resulted in small quantity; but, by comparison with coal, or coke-smelted iron, it was pure. England, however, in course of time became deforested in the neighbourhood of the existing iron-works,—the source of wood-charcoal thus failed, and pit-coal of necessity was obliged to be employed henceforth for the production of iron. Simultaneously with its adoption, the clay iron-stone began to supply the place, to a variable extent, of iron ore. The result was attended with both advantages and defects.

Iron admitted of being obtained in enormous quantities from these sources; but it had no longer the purity of the charcoal-iron of heretofore. Not only was the quality of the result deteriorated by the presence of impurities originally contained in the ore, but other impurities, especially sulphur, derived their

existence from the coal or coke employed as fuel. Against the presence of these impurities our iron manufacturers have continued, in one sense, to struggle up to the present time. The difficulty of getting rid of these impurities, however, has not been all to the disadvantage of our country. The fact is known even to general popularity, that the only difference between wrought-iron and cast-iron consists in the relation between the extraneous bodies—chemically speaking, impurities—in each; and the results of mechanical action upon the former. Iron absolutely, or chemically pure, is far more rare, and more difficult to obtain, than absolutely pure gold. It is, indeed, only met with in chemical laboratories, and very seldom there. Wrought-iron, however, may be practically considered as pure iron; and cast-iron as the latter combined with some four or five per cent. of impurities. That such impurities are not prejudicial to the nature of iron for all purposes and all uses, will be rendered sufficiently evident by a consideration of the products made of wrought and cast-iron respectively. Wrought-iron (that is to say, commercially pure iron) is almost infusible. By virtue of its malleability and power of adhesion under the operation of welding, it may be fashioned into a multiplicity of useful forms; but if any person casts his eye over the comparative number, and variety, of the products of cast and wrought-iron respectively, and reflects on the fusible quality which the presence of certain impurities confers, he will rise from the survey with the conviction that the existence of these impurities in iron, and the difficulties of evolving them, are not without their advantages. To these circumstances we owe the enormous development which the production, and working into shape, of cast-iron has attained in these realms; so that whilst we have been necessarily dependent upon the purer charcoal iron of Sweden, Norway, and Russia, as the basis of our steel, and wrought-iron, for exclusive purposes—cast-iron girders, and bridge-beams, made in this country, have been exported to every part of the civilized world.

Nevertheless, it was desirable that the capabilities of this country for the manufacture of iron should not be restricted to the operation of casting; but that we should be able to abstract the four or five per cent. of impurities from the cast material, and thus change it into wrought-iron. All the consecutive improvements in refining, and puddling, have had reference to this end; but, notwithstanding the comparative perfection to which these processes have been brought by Cort, and others,—notwithstanding the mechanical aids of hammering, and rolling, by which it was hoped that such impurities as could not be rendered capable of entering by combustion into volatile products, would be mechanically forced away,—the problem has never been solved of abstracting the impurities from cast-iron, and rendering the result equal in quality to the charcoal wrought-irons imported from Russia, Norway, and Sweden. All the chemical processes of iron-purification hitherto employed on the large scale, had been based on the operation of bringing highly-heated external surfaces of molten, or pasty iron, in contact with atmospheric air, and renewing the surface as often as the impurities which studded it had been burned away. The operations of refining and puddling were designed with

this object in view; and the operations of mechanical extrusion effected by hammering, or cylindrical pressure, were designed with the object, and successfully carried out up to a certain point, of accomplishing by mechanical means that which chemistry alone was unable to effect.

Refining Processes.—Every person who takes a passing glance at the operations of metallurgy in the aggregate, cannot fail to be struck with a certain functional similarity between the process of cupellation as applied to separate ignoble from noble metals, and the process of puddling, by virtue of which the impurities held by cast iron are removed from the latter. In both cases the general result is obtained by passing a current of air over a highly heated metallic surface. The puddling process (for perfecting which the world was indebted to the ill-requited Richard Cort) consists in placing partly-purified iron in a reverberatory furnace, and vigorously stirring it about so as to expose it to the action of the air: by which operation oxygen is rapidly absorbed, while carbonic acid gas escapes, giving the metal a bubbling and boiling appearance. As carbon escapes, the metal passes from a fluid to a spongy half-fluid mass; and in this state it is ready for the puddler. The metal is collected at the end of an iron bar, in a ball or bloom of sufficient size, which is swung through the air, and placed under the forge-hammer, to the crushing blows of which it is subjected; being turned and twisted in every possible direction, while sparks of fire dart from the surface, and liquid drops exude from the interior of the metal.

This is continued until the ball rings under the hammer, and the liquid drops give place to scaly masses. In this state it is passed through the rollers, in the grooves of which it is drawn out, and compressed, then doubled up and rolled; again heated, doubled up and rolled, until the process is complete. The new process, by which the reader will be at no loss to understand that we advert to the scheme devised by Mr. Bessemer, advances by one step further, as it is stated; and may be considered to be a nearer approach to the complete purification. By it a current of atmospheric air is forcibly projected not *over* but *through* a molten mass of impure iron; and it is assumed that by the chemical operation of this atmospheric blast, such impurities as are at once combustible, and the volatile results of combustion, will be expelled.

Now the combustible extraneous matters are for the most part carbon, sulphur, and phosphorus. The results of combustion of the first will evidently be carbonic acid and carbonic oxide, both volatile; of the second, sulphurous acid, also volatile; of the third, phosphoric acid, not volatile. The theory of the process is based upon the idea of removing the impurities by the heat developed from their own combustion; instead of employing other combustibles, themselves holding impurities.

A more beautiful, and more immediate, application of chemical knowledge to improvement of the iron manufacture it is impossible to conceive; although from its recent occurrence, and the probationary stage to which it has only yet arrived, we are precluded from treating of it without a certain feeling of constraint inseparable from the dawn of all new inventions.

Our remarks have already conveyed sufficient intimation of our cognizance that the indications of theory and the deductions of practice are not always accordant, to satisfy the reader of our freedom from any mere theoretical bias. At this early period, however, Mr. Bessemer, in common with every inventor who lays before the world a proposition which he believes in, and which a large section of the public is prepared to receive as an improvement on pre-existing modes, is probably experiencing some of the crosses and disagreeables inseparable from the office of pioneer in the regions of science or the arts. It is only a matter of common justice then, that those who have to speak or write of processes in his domain, should give them, so far as in them lies, a helping word of congratulation. Without, therefore, committing ourselves to a premature expression as to how much, or how little, the processes may accomplish, we are justified in stating that which is much more satisfactory to him and to us. The communications we have opened in relation to the papers in hand have necessarily thrown us into correspondence with various iron-smelters. On the premises of one of these—one of the largest, if not the very largest in the kingdom—Mr. Bessemer's process is about to be placed on trial, and under the most favourable auspices for a searching and impartial one; the result of which will be communicated to our readers in its proper place in the present volume.

But it becomes a question of very grave import, and one requiring the test of wear and tear of time as well as experiment to set at rest, whether there are not mechanical requirements in preparing malleable iron not comprised in Mr. Bessemer's process. Iron, like all other metals, has a strong tendency to crystallize at a given temperature; and an ingenious friend —theorizing on the subject—suggests an hypothesis which we have not met with before, that the puddling process supplies a mechanical as well as a chemical bond of union in the metal. The crystals, he suggests, are disturbed at the moment of formation, driven into each other by the stirring operation; and that the jagged edges of the particles thus become knitted or laced into each other in a fibrous mass.

This would seem to explain the tenacious and fibrous character of wrought-iron; and if so, it may be doubted if the new process will altogether supercede that of puddling, though it may greatly facilitate the operation.

Nor does it appear that Mr. Bessemer will be suffered to monopolize the attention of those interested in iron: Mr. Plant, of Holly Hall Colliery, Dudley, had patented, as early as July, 1849, a refining process, by which a current of air and steam is directed upon the iron while it is in the puddling furnace. Another process, patented in 1855, by Mr. Martien, of New Jersey, U. S., consists in passing currents of air and steam *through* the heated cast-iron as it runs from the blast-furnace. A third invention is by Captain Uchatius, Engineer-in-Chief of the Imperial Arsenal, Vienna, who has devised a method of producing every description of cast-steel, from crude pig-iron, in the short space of three hours, and the process was exhibited in London before a number of scientific and practical men to their entire satisfaction, as it is stated; although his experiments here were conducted in furnaces

not well suited to the operation. This process consists of running melted pig-iron from a crucible into a vessel filled with water, when the iron is converted into small granulated shot-like particles. A weight of twenty-four pounds of these granulated iron drops was mixed with crushed ore and filled into a crucible, which was placed on the furnace prepared for it. After the lapse of a period of two hours and three-quarters the crucible was taken from the furnace and the contents poured into an iron mould. When this was opened an ingot of steel weighing twenty-five pounds was exhibited to the company, and pronounced by competent judges to bear every external evidence of being perfect in quality. While this metal was being melted, an ingot of steel prepared by this process at the steel-works of Messrs. Turton, of Sheffield, was subjected to the steam-hammer, and a bar of steel produced from the ingot, which was pronounced to be of excellent quality by the practical men present. It is impossible to over-estimate the importance of these discoveries, should they bear the test of experiment on a suitable scale.

Between theoretical indication and practical confirmation, however, there is a bridge to be passed, which frequently breaks down and engulfs the inventor, through the interposition of some collateral obstacle. It may be that the processes of Mr. Bessemer and the other ingenious men named are in this category. Davy suggested the protection of the copper bottoms of ships by the attachment of zinc galvanic preservers. He caused the suggestion to be practically carried out, and *quoad* protection it succeeded. But Davy was foiled, and his process was rendered inoperative, through the interposition of a collateral circumstance, which had not entered into his calculations. The copper was no sooner prevented from undergoing solution, than its surface became harmless; sea-weeds and sea mollusks stuck to it, and the ship's course was impeded thereby. It may be somewhat thus with the inventions to which we have adverted; some collateral issue may interfere with the practical realisation of the inventor's hopes, in respect of the invention. It is always well to bear in mind these probabilities, seeing that they are the reflex of the history of most inventions; but nevertheless the theory on which Mr. Bessemer's operation is based is so simply beautiful, that now, at this early stage of it, before the ultimate practical issues of it are known, it is fitting that Mr. Bessemer should be cheered with the provisional recognition which a clear apprehension of principles, and a seemingly practical way of giving them effect, bespeak as justly his due. Whilst acting the part of *avant courier* to the practical monographs which follow, we only claim to look at the broad field of metallurgy from a theoretical point of view. In the puny microcosm of a chemical laboratory, where thousands of little appliances can be invoked to gain the end proposed by chemical analysis—it is possible, nay it is probable, that a chemist may not justly interpret the data which small operations evolve, into the less numerous, though individually larger, conditions of the practical man.

Advantages of Cast-Iron.—We have already intimated that the presence of impurities in iron as rendered by our smelting works, and the difficulties of removing them, are not barren of all good results; and we have adverted to the capabilities of cast-iron. Let us now contemplate the

subject of iron from the opposite point of view; let us assume that instead of the facility wherewith the *genius* of our smelting operations enables us to turn out enormous quantities of iron, cast into the form required, the genius of the process had been in the direction of depriving us of this impure material, but rendering us iron commercially pure—that is to say, in the state of wrought-iron. What difficulties would have beset us then! The operation of casting no longer possible, but every piece of manufactured iron being necessarily manufactured by the laborious opperations of forging, hammering, and welding—not merely would the price of iron for many purposes have been enhanced, but for numerous purposes to which iron is now applied it could not have been used at all. Contemplate the pieces of cast-iron which constitute the blocks of which Southwark Bridge is built, and imagine the circumference of blocks having the same form, weight, and dimensions, made of wrought instead of cast-iron, and *hammered* into shape: the thing would have been utterly impossible; it would be impossible even now, notwithstanding the aid of the ponderous steam-hammer. The ease with which a blacksmith heats, and welds, and fashions into shape, the half molten paste of glowing wrought-iron on his anvil would convey but feeble indications of the difficulties which beset these operations when conducted on a large scale. It is difficult to pronounce, and it would be invidious to make the attempt of fixing, the extreme limits or size of which a piece of wrought-iron admits of being forged. Practical effect is given to that operation to the extent of forging anchors, shafts and beams for the largest marine engines. These are achievements sufficiently difficult, and until lately critics were found—nay, indeed, they are to be found still—who confidently assert that much beyond these achievements of wrought-iron manufacture the operation could not go. Whether wrought-iron ordnance of large size could, or could not, be manufactured, having the strength necessary to ordnance practice, was a moot-point. Some years ago the Americans tried the experiment and failed; as a terrible accident from the bursting of a wrought-iron piece of ordnance painfully testified; since then Mr. Nasmyth repeated the experiment with so bad a result that it was considered by himself to be a failure, and he expressed himself very hopelessly respecting wrought-iron heavy ordnance. Nevertheless, a large piece has been made by an enterprising Liverpool firm, and presented to the Government. It is now whilst these remarks are written under process of trial; and hitherto it has stood all the tests deemed necessary, with complete satisfaction.

The result of the manufacture of this interesting piece of ordnance, and the trials to which it has been subjected, demonstrate that those who *ex cathedra* predicted so confidently that wrought-iron heavy ordnance could not be made (due regard being had to their strength), may have reason to alter their opinions. Confessedly, however, as between the casting of iron into a specified shape, and the welding and hammering of iron into a similar shape, the difference is enormous.

In addition to the mechanical difficulties attendant on the manipulation of wrought-iron—in addition to the difficulties of removing huge masses of it

from the forge to the anvil—the difficulty, moreover, of welding two or more large pieces together in such a manner as to give solidity to the welded joint—a chemical or molecular tendency of wrought-iron when retained at a glowing heat in large masses for long periods together, threatened to impose an insuperable barrier to the manipulation of wrought-iron in pieces much larger than anchors or marine steam-engine axes.

Crystallizing tendency of Wrought-Iron in large Masses.—It was found by Mr. Nasmyth in turning out his monster gun, that the iron had ceased to be fibrous, and had assumed a crystalline texture at its centre, thus losing the strength and tenacity which the fibrous condition would have given. It had been fully known that wrought-iron under some peculiar circumstances is prone to assume this condition. The axles of revolving carriage-wheels have been known to assume this crystalline state from vibration, after the lapse of time, and long usage, although they were originally fabricated of the best wrought-iron. Iron wire too, which, as all connected with metallurgy know, is necessarily made of the purest iron, occasionally assumes this crystalline state if long exposed to the agency of chemical forces; as, for instance, in a laboratory. Various hypotheses have been propounded to afford a rational explanation of this molecular change, from fibrous to crystalline condition. As regards the case of railway axles, the supposition appears rational, that constant percussion has given rise to the crystallized state; but the change experienced by iron wire is not so plausibly explicable. The crystallization of large masses of wrought-iron under the heating and cooling process, involved in the operation of welding, seems to admit of easier explanation. The result appears to be only a special illustration of a general resultant of the undisturbed play of cohesive affinity, tending as it does, if sufficient time and freedom of molecular motion be given, to assume the most perfect cohesive state of which matter is capable—that is to say, the state of crystals. Had the result of crystallization been inseparable from the practice of welding large bars of iron, there would have been an end to wrought-iron ordnance of large calibre; there would have been an end also to the production of any pieces of wrought-iron considerably larger in dimensions than the forms hitherto produced. We shall look forward, therefore, with some interest to the monograph on the working of wrought-iron in large masses, promised us by Mr. Clay.

Impressed with specialities as the metals are, each one conducing to certain purposes better than any other—nevertheless, with the exception of iron, these capabilities are numerous, and one generally admits of being substituted for another. But no civilized race could exist as such without the co-operation of the metal iron. For the greater number of purposes to which it is applied, there is no efficient substitute. True, the ancients did manage at one time to manufacture cutting instruments out of bronze; true, that Sir Francis Chantrey in our own times, in his reverence for classic metallurgy, caused a bronze razor to be made, wherewith he shaved; nevertheless, we doubt whether any one less ardent in the love of ancient metallurgy than himself would have borne contentedly the daily infliction.

Literature of Metallurgy.—Metallurgic history admits of division into three periods. The first comprehends the time which elapsed from the earliest historical epoch to the days of Pliny, or the first century of the Christian era. The metallurgic records of the period are contained in Holy Writ, also in the writings of Strabo, Dioscorides, Pliny, and others, comprehending proofs of the knowledge of gold, silver, mercury, copper, tin, lead, and iron. The second period includes the time which elapsed between Pliny and Agricola, or from the first century of the Christian era to A.D. 1550. At the commencement of this epoch mines were worked in Asia Minor, Spain, &c.; in the seventh century was commenced the working of mines in Bohemia and Saxony; in the ninth century, mines in Rammelberg were commenced; the knowledge of arsenic was first acquired in the fifteenth century; in the fifteenth century also of bismuth; and in 1540 there appeared at Venice the first modern systematic work on mining, smelting, and metallurgy. The third mineralogical period extends from the time of Agricola, who may be justly considered as the father of metallurgy, to our own days. In his collated metallurgic work, published in 1548, under the title "*De re Metallica*," are to be found the first precise instructions concerning the arts of mining and smelting. Immediately subsequent to the appearance of Agricola's treatise, "*De re Metallica*," numerous others, of unequel pretensions, began to appear; but their chemical hypotheses were tinctured with the errors of the phlogistic theory; and not until the final overthrow of that theory by Lavoisier was it, that both these arts assumed the utility which we find at the present time. In the years extending from 1801 to 1810, both inclusive, Lampadius of Freiberg published a valuable collection of facts relative to metallic operations: giving form and substance to a large mass of disconnected facts relative to these matters, and known to various persons in his time. The second series of the metallurgic fruits of Lampadius appeared between the years 1817 and 1827; thus preparing the way for the new system of metallurgy by Karsten, which appeared in the years 1831 and 1832. In 1841 appeared a small but comprehensive volume by Wehrle,—soon followed by Sheerer's valuable treatise entitled *Lehrbuch der Metallurgie*, to which the merit is attributable of having aggregated the numerous branches of knowledge which constitute metallurgy into the shape in which we at present find them. In our own day, the German metallurgist Bruno Kerl has contributed an admirable manual in his *Metallurgischen Hüttenkünde*. But perhaps the largest amount of light has been thrown on British metallurgy by the admirable lectures and experiments of Dr. Percy, at the Museum of Geology. It is impossible to praise those labours more highly than they deserve, or to over-estimate their influence on the future of metallurgy.

The art of metallurgy, particularly considered, has reference not alone to the chemical constitution of metallic ores and the method of extracting and preparing them, but it also takes cognizance of all that relates to the construction of furnaces, the utilization of collateral processes, the strength of materals employed in furnaces, and the necessary machines. It also involves a knowledge of the chemical principles concerned, so that the metallurgist may not only be able to apply on the large scale the most promising indica-

tions of science, but also to test the value of large processes by the more delicate systems of the laboratory.

Classification of Metals.—Before indicating the chemical principles upon which each special process of metallurgy is based, it will be desirable to arrange the metals in classes, according to the several characteristics which they present. Great specific gravity is so prominent a characteristic of metallic bodies, viewed in the aggregate, that anterior to the discovery of potassium, sodium, and the other alkaline and terrigenous metals, the quality was thought to be inseparable from the metallic condition. So far, however, is this from the truth, that lithium—the metal of the alkali or alkaline earth lithia: it may be said to be intermediate between the two—is the lightest known solid, metallic or non-metallic, in all nature. Based on a consideration of the quality of specific gravity, then, we arrive at a division of metallic bodies into the light and the heavy. In a purely chemical sense, such a division has no value; but it is otherwise to the metallurgist. Inasmuch as the metals of the alkalies and alkaline earths—that is to say, the light metals—are only produced by complex and refined chemical processes, they may be considered as lying without the domains of metallurgy. It is only with the remaining class (the heavy metals), therefore, that the metallurgist has to concern himself, and to which the reader's attention throughout this introduction and the succeeding monographs will be exclusively directed. Contemplating the heavy metallic bodies, in a practical or metallurgic sense, with reference to their subdivision, their various demeanour with regard to oxygen, and their general relations to that extensively diffused non-metallic element, we have a natural as well as a ready means of classification. It has been calculated that almost two-thirds by weight of our globe's constituents—solid, liquid, and gaseous; its vegetables and its animals and minerals—consist of oxygen. The chemist need not to be reminded of the powerful tendency to combustion which oxygen manifests, especially with metals. Unquestionably the most considerable and the most important metallic ores are oxides, or combinations with oxygen. It is natural, therefore, that the metallurgist should seek, in an examination of the relations of metals to oxygen, the basis of their practical subdivision. Five well-marked subdivisions, founded on these peculiarities, admit of being established. They are as follow:—

1. Metals having a strong tendency to combine with oxygen, and to generate bases. These metals admit of arrangement in three sections.

§ (*a*). Metals whose oxygen-compounds are basic, or have the property of bases. They are zinc, cadmium, lead, and uranium.

§ (*b*). This section has only one representative, *i.e.* arsenic, or arsenicum; a metal the peculiarity of which is, that its combinations with oxygen are acid, not basic.

§ (*c*). Metals which form both acids and bases by combination with oxygen. They comprehend copper, nickel, cobalt, bismuth, tin, copper, manganese, iron, antimony.

2. Metals the tendency of which to combine with oxygen is but slight:

comprehending gold, silver, platinum, and mercury. The three former are sometimes called "noble metals."

The relative fusibility of metals also affords a good means of practical classification. Having reference to this difference, five well-marked subdivisions admit of being established.

1. Fusible, and remaining liquid at the lowest heat of temperate climes. There is only one metal which answers to these conditions: it is mercury.

2. Fusible between 392° and 788° F., and passing off into vapour when the heat is still further raised. The metals represented by this subdivision are zinc, cadmium, lead, bismuth, antimony, and arsenic or arsenicum.

3. Fusible at temperatures above 1830° F.: copper, silver, gold.

4. Not completely fusible by the strongest furnace-heat: manganese, iron, nickel, cobalt, platinum.

5. Fusible in the hydro-oxygen jet: chromium.

Alloys.—Having taken a cursory survey of the classes and subdivisions of which metals, practically considered, are susceptible, we shall now proceed to describe the principal compound forms of which metals are susceptible. The first of these which presents itself is the class of alloys.

The term alloy in its most general acceptation means the mutual combination of two or more metals. When one of the metals, however, entering into combination is mercury, the result is not usually termed an alloy, but an amalgam. Alloys are practically interesting to the metallurgist in two ways: either the metals to which a metallurgic process of extraction is applied are found in the condition of native alloy—*i.e.* one naturally existing—or an alloy results as the consequence of an intermediate metallurgic process. The native state of gold with silver, and of platinum with rhodium, iridium, palladium, and its other associated metals, present familiar instances of native alloys. The intermediate combination of lead and silver resulting from the metallurgic process of reducing galena, furnishes a good instance of the second. At the present time the belief prevails—we may even say it is universal—that alloys are not always mere mechanical mixtures of different metals, but are constituted in accordance with the laws of definite chemical combination; being no less atomic (to adopt the language of the atomic theory) than oxides and salts are atomic. It would lead us too far from the subject of metallurgy to adduce the various arguments which exist in favour of the belief; and indeed a superficial glance at the bearing of the hypothesis would perhaps induce the practical metallurgist to pass it by as devoid of utilitarian interest. Few subjects, however, are more intimately related to the utilisation of metals than those involved in the seemingly abstract question of chemical composition, or of mere admixture, in relation to alloys. An illustration very much to the point is afforded by the manufacture of the alloy called "silver-steel."

In the course of some experiments performed by Professor Faraday and Mr. Stodart, they discovered that silver when fused with steel in certain given proportions entered into mutual combination, and formed a valuable alloy. If, however, the quantity of silver was increased above a certain pro-

portion not yet quite ascertained, the excess of silver was extruded from the metallic mass during the process of cooling. This result at once affords testimony as to the chemical constitution of the alloy, and points to the practical advantages likely to be derived from a solution of the question—"What are the exact, or atomic, proportions in which steel and silver can combine?" Granting, for the sake of argument, that the silver-steel be so far superior to ordinary steel as to warrant its manufacture, the conclusion follows that it is a point of the utmost importance to determine the exact maximum amount of silver which steel can take up. Not merely would the addition of every grain of silver beyond the indicated proportion be an unnecessary expense, but such of the uncombined silver as might be locked up mechanically in the alloy during the cooling process would lessen its strength, and, indeed, impart a general deterioration of quality.

As a general rule, it may be stated that all metals which form alkalies have a particular tendency to unite with those which form acids. When two metals are alike in their affinities for oxygen, they do not readily combine, and may often be separated by crystallization only, when both metals absorb nearly the same quantity of oxygen in forming their oxides. Nearly all chemical combinations liberate heat. Zinc and copper, when melted together, produce a high temperature. Where a mere mechanical mixture of metals occurs in an alloy, it is characterized by distinct crystals being formed with one metal, between which the other is visible. When an alloy is formed with proper equivalents, no such disconnected crystals are observed. In cooling a melted alloy, that composition which is most refractory crystallizes first, and that which is most easily reduced to fluidity is compelled to occupy the spaces between the crystals. Thus copper and tin are fusible; but in cooling, copper-tin crystallizes first, and tin-copper last. Iron and arsenic are very fusible; but in cooling, iron-arsenic crystallizes first; in consequence, the surface, when cool, exhibits a perfect net-work of bright lines in regular forms. In all of these compounds, however, portions of each alloy are contained. When a bar of cold lead is dipped in mercury, the pores of the lead become filled with mercury, but the mercury also absorbs lead. When iron is strongly heated while imbedded in carbon, as is the case when blistered steel is produced, the carbon penetrates to the very centre of the iron rods; but no iron is imparted to the carbon, because its atoms are not moveable.

Alloys are more fusible than the individual metals, and will melt at a lower temperature than the mean would indicate. Though tin melts at 500°, and pure copper at 2,500°, equal parts of copper and tin do not melt at the mean 1,500°, but at a lower heat. Pure iron is extremely refractory; but when combined with arsenic and phosphorus, it may be melted in a cast-iron pot without adhering to it. Again, a composition of three metals is still more fusible than their various degrees of melting would indicate; and if their component parts are according to the laws of chemical affinity, the melting point is lower still. Need we repeat, after this, how important is the study of forming alloys in the smelting-furnaces? It is the degree of fusibility of the slags and metals, which determines the cost of the process.

Iron is rendered fusible by the presence of carbon; but when that substance is removed it becomes refractory, and can hardly be melted. Tin is refined by oxidizing or evaporating sulphur, arsenic, and other matters; a process which renders tin less fusible and more tenacious. Zinc melted in an iron pot, and exposed to the air, exhibits dross on the surface; its fluidity is diminished, but its malleability is increased. A layer of carbon, or common salt above ashes, prevents these phenomena.

Alloys are generally harder than might be expected from their constituents; although there are exceptions to the rule. Silver and arsenic, render iron hard, although both metals are soft in themselves; copper and tin, both soft metals, become hard when melted together in certain proportions; and zinc and copper make brass soft. Antimony causes all metals to become hard, but very brittle. Iron mixed with a little antimony will cut glass.

The ductility of alloys is sometimes greater than might be expected; in others, it is more brittle than the original metals. Alloys of zinc and lead, are very tenacious; lead and antimony, very brittle. Any alloy which is slowly heated and gradually cooled—annealed, that is—is softer than when the compound is suddenly chilled; hence the hardness of chill-cast iron.

The above-mentioned examples are types of many others, demonstrating that though metallic alloys occupy a less prominent position than metallic oxides, sulphurets, chlorides, &c., nevertheless, the conditions which regulate their existence must not be neglected by the metallurgist.

The separation of the constituents of metallic alloys is accomplished by several methods. Of these the one most obviously suggested by theory consists in a gradual application of heat up to the point of melting the more fusible metal, and leaving the other unfused. In this way lead is separated from an alloy of that metal with copper. Scarcely less obviously suggested by theory is the application of heat to effect the volatilization of one of the metals entering into an alloy. In this way is mercury separated in practice from alloys (amalgams) of mercury with gold, and mercury with silver. In this way also is silver obtained from argentiferous zinc.

The metallic constituents of some alloys admit of separation by subjecting them to fusion and gradual cooling. During the cooling process the metals of an alloy will in some cases separate in layers according to their specific gravity. In other cases the separation ensues from one of the constituents shooting into crystals and becoming solid, thus furnishing a means of its removal. The celebrated process of effecting the separation of silver from lead, known as Pattinson's crystallization process, is of this kind; but the most extraordinary circumstance in relation to it is, that the lead or the metal of lesser fusibility is that which first crystallizes out. The rationale of this curious phenomenon has never been explained. Occasionally separation of two or more metals constituting an alloy is effected by means of acid-solution. The process of quartation by which silver is dissolved out from an alloy of that metal and gold, will serve as a familiar illustration.

Metallic Oxides.—We have already said that these are the most numerous and the most important of metallic ores. The smelting of them depends

on an application of the best practical means of removing oxygen. The relations of metals to oxygen, and the relative facility wherewith they evolve oxygen wholly or partially, have all been accurately determined by the chemist. On the large scale, the exact agents employed in the laboratory for effecting deoxidation cannot always be applied; nevertheless, chemical principles have to be followed as closely as circumstances will permit: therefore it will now be proper to explain the relations of different metals to oxygen in respect of the comparative difficulty of removing that element from them.

The reduction of metallic oxides may be effected by the dry and the moist processes. It is the former, however, which immediately concerns the metallurgist, and to which we purpose to direct the attention of the reader. The noble metals gold, silver, and platinum are characterised, as is well known, by the difficulty wherewith their respective combination with oxygen admits of being effected. Conversely, the respective oxides of these metals are characterised by facility of decomposition. The application of heat alone, without the contact of any extraneous body, suffices to liberate oxygen from the oxide of the noble metals, and of course to evolve the metal.

All other metallic oxides require the agency of a second body to effect their reduction, mere application of heat being insufficient; and a consideration of the deoxidizing materials at the disposal of the metallurgist, and employed by him, opens a field of great utility and interest. The deoxidizing agent of greatest importance to the metallurgist is coal in its several varieties, and the derivative materials yielded by its combustion. When coal is burned in a furnace, the first product of combustion may be considered to be carbonic acid gas; but inasmuch as the latter is readily decomposed by permeating ignited pieces of solid carbon (coke), losing a portion of its oxygen, and becoming carbonic oxide gas,—we may say that the products of the combustion of coal are firstly carbonic acid;—secondly, carbonic oxide and carbonic acid; and lastly, carbonic oxide alone. The latter in combination with heat is a most powerful deoxidizing agent. Were it not for the production in furnaces of carbonic oxide gas—were it necessary that the solid carbon of the coke should be alone the deoxidizing body, then it follows that every particle of the ore to be reduced must be brought into intimate contact with the reducing body; a process involving more care and trouble than are compatible with large metallurgic operations. The reducing agent being a gas, there is no longer a necessity for that intimate mixture of fuel and ore which would otherwise be necessary. Provided that the gaseous results of combustion are placed under circumstances of readily permeating the ore, the necessities of practice are amply subserved. In many cases of reduction of the oxides of lead, silver, tin, and copper, the fuel is actually contained in a furnace by itself, the ore to be reduced being in another. There is great difference as to the amount of heat at which the reduction of different metallic oxides can be effected. The oxides of lead, bismuth, antimony, nickel, cobalt, copper, and iron, require a strong red heat; whilst the oxides of manganese, chromium, tin, and zinc, do not lose their oxygen until heated to whiteness.

Combinations of the metallic ores with oxygen take place in certain definite proportions, and, so far as relates to most metals, in definite quantities. There are three oxides of iron which interest us here, namely—the protoxide of iron, which is a strong base; the magnetic oxide, a feeble base; and the peroxide, which is more of an acid than a base. Peroxide and protoxide of iron, both infusible by themselves, form a fusible slag. Arsenic forms, in all stages of oxidation, an acid which never melts with any other acid, or with highly oxidized metals; it being a requisite condition of fusibility, that one of the constituents in which the other is merely suspended must be fusible. This chemical relation admits of a wide range, nor is the same substance in all its relations of the same character.

The oxides of iron are always basic as to silic acid, but they are acid in relation to oxide of lead. The study of the metallurgist must be directed to these chemical relations, as well as to the degree of fusibility of the compounds and the relation they bear to the metal to be produced under their influence.

As a rule, it may be stated that the compounds of single equivalents of metal and oxygen constitute a base or alkali, and that the addition of more oxygen destroys that property. Thus the protoxide of manganese is a strong base, and precipitates the protoxide of iron from a slag; but the peroxide of manganese is driven out by the protoxide of iron. When carbon is present, one atom of oxygen is absorbed by it from the peroxide of manganese, and the iron is again driven from its union. This affinity of oxygen for metal is most difficult to be overcome at a state of oxidation half-way between the extremes. Protoxide of tin is easily converted into metal, so is peroxide; but the sesquioxide, intermediate between the two, presents much greater difficulties. Practically it is usual to smelt with the highest oxides, and convert the ores into that state, in order, not only to remove the oxygen from the metal, but also to produce so high a heat as to fuse the metal at the precise moment when the oxygen is removed.

Hydrogen and carburetted hydrogen gases must not be omitted in our enumeration of the deoxidizing agents employed by the metallurgist. The latter agent, carburetted hydrogen, is evolved during the combustion of coal; the former, when employed, as it is, though sparingly, as a metallurgic agent, is developed by transmitting aqueous vapour over red-hot coke. When this gas is produced by dissolving iron or zinc in a diluted acid, it is always moist, and invaluable for the performance of any delicate experiment; for the reduction of metallic oxides it should be dry, and free from any foreign substance. Carburetted hydrogen or coal-gas is used to reduce oxides under a low heat, the carbon which is precipitated in the formation of the metal being removed by smelting. Hydrogen or carburetted hydrogen is applied in the assaying process, by leading it into a glass tube which contains the ore specimen in a proper form already heated. A gentle current of gas is passed over the ore until no more is burned by it, which is manifested by the escape of the gas in a pure form.

Next to metallic oxides, metallic sulphides are of the deepest importance

to the metallurgist. Their reduction generally involves the operation of roasting, a process to be treated of hereafter.

Sulphides.—All metals combine more or less with sulphur, and form sulphides when sulphur is brought into contact with the metal, in the absence of oxygen or chlorine. When oxides are treated with sulphur in sufficient quantities to absorb all the oxygen in forming sulphuric acid, the sulphur remaining combines with the metal. When sulphates are treated in the presence of carbon or hydrogen, the oxygen of the sulphuric acid is abstracted, and sulphides remain. The chemical relation of sulphur to metal is similar to that of oxygen—that is, the number and equivalents of the sulphides correspond with the number and equivalents of the oxides of the respective metals—causing them to be more fluid and brittle when cold, and impairing their ductility when hot. Large quantities of sulphur cause a low degree of fusibility, which is shown in the sulphurets of antimony, lead, copper, and iron, the fusibility in each decreasing more rapidly than the evaporation of sulphur. Iron pyrites melts at a low red heat; but when reduced to half its original quantity, by evaporating the sulphur, it requires a strong white heat to melt the sulphides. The presence of free oxygen is required for the removal of sulphur; nor can it be removed entirely when carbon, hydrogen, or any other reducing agent is present, an oxidizing influence and thorough exposure of the metal to oxygen being necessary.

Nevertheless, the partial decomposition which certain metallic sulphides undergo, when heated without the access of atmospheric air, is to the metallurgist a consideration of importance. Galena treated in this way suffers partial decomposition; so, in like manner, does the monosulphuret, or monosulphide of copper,—a sufficient amount of sulphur being evolved from it to yield disulphide of copper as the permanent fixed result. The higher sulphur combinations of iron, or, chemically speaking, the sulphur salts of that metal, generated by the combination of two sulphurets or sulphides, also give a portion of their sulphur when exposed to high heat in close vessels. Monosulphide of iron, however, does not yield up any of its oxygen by the mere process of heating in close vessels. The sulphide of zinc (zinc blende) is unchanged by the highest temperature; so, in like manner, is the sulphide of silver. The sulphides of gold and of platinum are decomposed when heated into sulphur and their respective metals. The sulphide of mercury can be distilled without change. Sulphide of antimony melts at a high red heat, afterwards distils over unchanged. The mono- and the ter-sulphide of arsenic (orpiment and realgar) both fuse, and distil without undergoing any decomposition.

By far the more important and usual method, however, of effecting the reduction of metallic sulphides, consists in exposing them to the combined agency of heat and atmospheric air—constituting, in point of fact, the operation of roasting. Usually, the change which ensues during the operation of roasting, is the conversion of sulphur of the sulphide into sulphurous acid gas, which escapes; the original sulphide, either losing a part of its sulphur, and

being thus reduced to the lower stage of sulphurization, or else, losing the whole of its sulphur, oxygen is absorbed in place of the latter. Occasionally the sulphurous acid first generated absorbs the necessary amount of oxygen, to change it into sulphuric acid, which combining with the metallic oxide simultaneously generated, gives rise to the sulphate of an oxide. This latter is the case when galena (sulphide of lead) is roasted, the final result of the operation being oxide of lead, and sulphate of oxide of lead. This change is eminently favourable to subsequent metallurgic operations of which galena is the subject. If the galena be argentiferous, the following reactions ensue. The mixture of oxide of lead and sulphate of the same oxide being heated to whiteness in contact with silver (of the argentiferous galena), oxidizes the silver by decomposition of the sulphuric acid, of the sulphate and oxide of lead; hence there results a mixture of oxide of silver and of lead—a mixture easily dealt with, and deoxidized by a subsequent operation. The sulphide and disulphide of copper are changed by roasting, into dioxide of copper and sulphurous acid, and sulphate of the oxide of copper, which latter, when the temperature is raised to the highest pitch, evolves the whole of its sulphuric acid and oxygen; leaving metallic copper. Monosulphide of iron by roasting undergoes many progressive changes; beginning with the formation of protoxide of iron and sulphurous acid, and ending in the development of sesquioxide of iron. Sulphide of zinc (zinc blende) slowly changes under the influence of roasting, first into oxide of zinc, and sulphate of the oxide; then into subsulphate of the oxide; and, lastly, into oxide exclusively. Sublimate of bismuth changes, under the influence of roasting, into oxysulphuret: sulphide of silver is decomposed, and yields metallic silver. Tersulphide of antimony changes under roasting into antimonious and antimonic acid. The sulphide and the sesquisulphide of arsenic are changed into arsenious and arsenic acids.

By a modification of the same process, sulphide of nickel admits of decomposition into a mixture of oxides and sesquioxides of that metal. Sulphide of cobalt is also decomposed into a mixture of oxide of that metal and sulphate of the oxide. Finally, the sulphides of gold, platinum, and mercury are also reduced to the metallic state, sulphurous acid gas being evolved.

Another element equal in importance to oxygen, requires the attention of the metallurgist. CHLORINE has a tendency to induce metals to crystallize, and causes consequently fluidity and brittleness. Chlorine removes all other matter from metals when the latter are in a state of fusion. Carbon, sulphur, and phosphorus are drawn off by it, and, if the heat is continued, the chlorine itself escapes with a portion of the metals, but only when a minute proportion is present; it is thus a powerful element in the purification of metals. Lead smelted from chlorides is purer than from oxides and sulphurets, and its proper application to smelting and refining purposes has a most beneficial influence. Zinc does not readily combine with iron unless chlorine be present; it removes oxygen from the protoxides, thus purifying the surface and preparing it for closer union with an alloy. All metals smelted under the influence of chlorine, are inclined to oxidize, unless it is removed entirely. It

is harmless to the metals, powerful as a means of fluxing slags and ores, and producing fluidity; its use, therefore, ought to be much more extended than it has been.

Calcination, and Roasting.—These processes are more frequently made use of than any other operation had recourse to by the practical metallurgist for effecting the elimination of sulphur and other volatile substances from the ores which are sulphides or sulphurets. No agency is so commonly employed as this, although the mention of a few others should not be omitted; amongst these may be enumerated the combined application of heat, and aqueous vapour; of heat, and the decomposing agent of a metallic oxide; finally, of heat, and the decomposing agency of alkalies, alkaline earth, and their combinations. As a general rule, however, we may regard all other metallurgic processes having reference to the decomposition of sulphurets, rather as preliminary *assay* operations, than the final processes capable of adoption by the manufacturer.

The process of calcination is generally adopted to remove volatile substances. Iron and zinc ores are heated to expel water from them, and iron, lead, and zinc are calcined to expel carbonic acid. Water will escape by the application of a gentle heat; but if much clay be present with the ore, it adheres tenaciously to the mineral. Calcination is most conveniently performed in a crucible, because no stirring of the mass is required. The heat of an air furnace is generally sufficient for the performance of this operation.

The operation of roasting is performed by various processes depending on the nature of the ore, the quantity of the fuel, and the object in view. Roasting in heaps in the open air is the method most generally adopted with iron ore, pyrites, and ores which can bear a strong fire. The operation consists in spreading over a plane surface of ground billets of wood, or lumps of mineral coal, from six to eight inches thick, the interstices between the coarse fuel being filled up with chips of wood, charcoal, coke, or coal. Over the fuel thus prepared, according to the kind of ore, is spread a layer of from twelve to twenty-four inches in thickness. Coarse ore, which will bear a great heat, may be piled pretty high; but fine crushed ore from the stamps, and ores which smelt easily—such as sulphurets or arseniurets—should not have too much coal in a body, nor the ore piled over high.

Alternate beds of fuel and ore are thus formed, and roasting heaps accumulated, which are in many cases extremely large, retaining the fire for a long time.

Roasting means heating a substance to such a point that the mineral does not melt, but at which the volatile substances are expelled, and as much oxygen combined with the ore as it can absorb. In some cases, chlorine, carbonic acid, or steam is required along with the air; in other instances, the object is to oxidize the ore to a higher degree, to drive off volatile matter, or to reduce the ore to metal, and evaporate it, as in the case of arsenic, zinc, and antimony.

The tendency of carbon to unite with metals is slight and circumscribed; only two metals, considered in a metallurgic sense, are amenable to this kind

of combination,—copper and iron: nevertheless, they are the most important of all metals; and without the carburets of iron (cast-iron and steel), the most useful purposes to which iron is now applied could never have been subserved. The union of carbon with copper is only productive of inconvenience, and the care of the metallurgist is devoted to effect the removal of the former; but in the case of iron, though on one hand the removal of carbon is a metallurgic process highly desirable in order that soft wrought-iron may result, nevertheless, on the other hand, the problem of causing the union of soft iron with carbon, is one of importance equally great; for on its successful issue depends the conversion of iron into steel.

As regards the theory of the metallurgic processes had recourse to for effecting the removal of carbon, they are such as naturally suggest themselves from a chemical consideration of the properties of that non-metallic element. Carbon is the most ordinary material of combustion known to man; it is the very type of combustible bodies. To deprive a carburet of its carbon, therefore, nothing seems more natural than to burn it away. This is indeed the process usually followed. It lies at the basis of iron-refining and puddling; still more obvious is the application of the combustive energy in the new operation of Mr. Bessemer. Combustion, nevertheless, is not the only agency taken advantage of for effecting the removal of carbon from iron. A very elegant process for converting steel or cast-iron into soft or decarbonized iron, consists in exposing an article fabricated of either of these materials, to heat in contact with iron oxide. The chemical agencies thus involved are sufficiently obvious. The oxygen by its affinity for carbon at an elevated temperature unites with it, forms carbonic acid, and is evolved, leaving the iron, to the extent of the removal of carbon thus effected, pure. The process in question unfortunately has but an application restricted to a limited number of articles of inconsiderable dimensions.

The union of soft iron with carbon, or, in other words, the formation of steel, is usually effected by the process known as cementation. It consists in stratifying bars of iron with charcoal in an iron case, and subjecting the whole to furnace heat, until the desired union of the carbon with the iron has been effected. The chemistry of this union is very peculiar; furnishing an almost unique example of combination ensuing between bodies neither fluid nor gaseous, and contravening the long accepted chemical axiom, *corpora non agunt nisi fluida*. Perhaps however, after all, the exception is more apparent than real. Laurént was of opinion that the carbon thus entering into combination with iron, and forming steel, became actually vaporized by the heat employed. Stammer advances another hypothesis: he believes that the play of affinities resulting in the union of carbon with iron, is more complex than had up to his experiments been imagined. He infers that a mixture of iron and oxide of that metal, when brought to an elevated temperature, as in the process of cementation, in contact with carbonic acid gas, robs the latter of its oxygen, thus liberating carbon; which, whilst still in this condition, unites with the metal to form a carburet.

Though the great magazine of phosphorus in creation is the bones, and

some of the fluids of animals, nevertheless, phosphoric acid, combined with oxides of metals and constituting phosphates of these oxides, give rise to a small though important group. Perhaps no element wherewith metals are naturally found in combination is more difficult to separate effectually, or exerts a more deteriorative influence when present, even in minute quantities, than phosphorus. The processes usually had recourse to by the metallurgist for effecting the separation of phosphorus, are based upon the employment of some body which manifests a strong affinity for phosphorus at elevated temperatures. Of this kind is chalk, which is sometimes employed for the purpose of separating phosphorus from iron.

Occasionally, though not very often, the metallurgist has to deal with the extraction of metals from their salts, both oxygenous and haloid. This kind of extraction, too, involves not merely the dry process, but also the use of chlorine and of acids. Platinum is a metal which has to be dealt with exclusively by the process of moist solution. Limiting our observations for the present to the case of dry operations, we find that certain metallic salts are decomposable by heat alone, whilst others require the agency of some collateral reducing body. Most of the salts of the metals, gold, platinum, and silver, are characterized by their facility of complete decomposition, by the mere application of heat. Of this change, the chlorides of gold, of platinum, and the sulphate of the oxide of silver, present familiar examples. Many other metallic salts when subjected to the agency of heat, instead of being reduced to the metallic form, yield their several oxides. The sulphate of iron and the sulphate of copper are of this class,—yielding, when sufficiently heated, oxides of the respective metals.

To the practical metallurgist, the most interesting series of saline decomposition by fire, and deoxidizing materials, are those in which the sulphates of different metals are concerned. Sulphates differ merely from sulphides (viewed as to their composition) in the mere circumstance that the former contain oxygen, whilst the latter do not: hence, when sulphates are heated in contact with coal, coke or other deoxidizing matter, oxygen is frequently removed and a sulphide remains. The relative facility of this kind of decomposition varies for different sulphates, but it furnishes a type of most of the decompositions which ensue when sulphates are exposed to the combined agency of deoxidizing materials and heat. Of all the salts which come under metallurgic cognisance, the chlorides next to the sulphates are most important. The reduction of the chloride of silver forms the basis of the mode of silver extraction followed in America, Hungary, and various parts of Europe; the reducing agent being iron. Various other methods of reducing chlorides to the metallic state are followed in the processes of metallic assaying; and, although not much involved in the practice of metallurgy on the large scale, are still of great importance to the metallurgist. The reduction of chloride of silver by heating with alkalies,—of the chlorides of certain metals by the contact of another metal; and of the chlorides of gold and platinum by sulphurous, oxalic, arsenious, and formic acids, sulphate of iron and a few other reagents—are familiar examples.

CHAPTER II.

SPECIAL METALLURGIC OPERATIONS.

We now come to the principles on which metallurgic processes are based, and the practical application of these principles. Mechanical and chemical sciences are here involved,—the former to effect a due comminution of the extracted ore from foreign impurities; the latter to complete this separation and evolve the metal in a condition as near that of absolute purity as may be possible or desirable. The mechanical part of metallurgy can only be discussed advantageously hereafter; in this introduction, therefore, we shall limit ourselves to an exposition of the chemical principles of metallurgic operations.

Between abstract chemistry, if the term be allowable, and technical chemistry, there seems a wide difference at a first glance. The only real distinction between them, however, will be found to be one of degree. The principles are the same, and both are amenable to the same laws: the laboratory chemist, however, having more agents at his command—being little amenable to considerations of profit—more readily carries these indications out to their several finalities.

The chemical part of metallurgy has for its object the separation of various substances, and the isolation of a few, by the operation of chemical affinities; being amenable thus to ordinary rules of chemical guidance, the first of which is based upon the law that chemical action takes place (with few exceptions, and those doubtful) between portions of matter the cohesion of which is slight. Reversing the proposition, we may also say that chemical decomposition is effected by loosening the state of cohesive affinity.

Of the three forms in which matter is found, namely, the solid, the fluid, and the gaseous state, respectively, it is evident that the two latter are most under the control of cohesion;—gases, indeed, are often said to be absolutely devoid of cohesion as between their particles; a proposition which, though chemically unsound, may be considered to be practically correct.

The metallurgist, then, in effecting his numerous decompositions, proceeds to diminish the cohesive force by which the particles of his material are held together. He begins by mechanical processes—by hammering, grinding, stamping, &c. When these can go no further, he has recourse to chemical means. The problem now is to liquefy, or to gasify—usually the former, though many important mineralogical operations involve the production of gas, or at least of vapour; for gases and vapours may be generally regarded as identical. Supposing liquefaction to be the object in view, the metallurgist has the choice, theoretically, of dissolving his substance in chemical menstrua or of fusing it by heat. The former alternative is superior in the correctness of its results, and for that reason is usually adopted by the laboratory

chemist; but it is so expensive, and slow, and inapplicable where large masses are concerned, that it is never adopted by the metallurgist, otherwise than by necessity. With the exception of platinum and its associates, all worked exclusively by the process of solution in chemical menstrua—by the moist process, in point of fact—gold occasionally, and a few of the common metals under certain peculiar conditions, the moist process of effecting solution of cohesiveness may be regarded as beyond the pale of applied metallurgy.

We have thus limited the metallurgist to the agency of fire; and we have assumed, as is most usual, that the object of furnace-heat shall be to reduce the material to the condition of fluidity. We might, therefore, at once, pursuing the thread of demonstration, enter upon the theory and operation of fluxes, were it not that a case of effecting chemical decomposition by the formation of gas or vapour sometimes precedes, and therefore claims precedence in our remarks. Many ores either contain substances naturally volatile, or which generate, under the combined influence of heat and air, volatile combinations. Sulphur and arsenic are prominent examples of this kind, and serve well to illustrate that application of a chemical law which is involved in the metallurgic process of roasting or calcination; respecting which sufficient particulars in an earlier part of this introduction have been already given.

The process of roasting is variously modified to accord with the peculiarities of certain metals, or to gain the precise end desired. In some cases it is no more than the process known to chemists as dry distillation; in other cases, its success depends on the combined agency of an atmospheric current as applied, for instance, to the evolution of antimony.

Though the metallurgic operation of roasting involves a well marked case of gasefaction applied to a definite end, yet similar results are obtained under different forms of apparatus. The operations involved in the production of mercury and zinc are familiar examples. Both these metals are remarkable for their extreme volatility, the first especially so: hence the process of metallurgy adopted in their production is not one of smelting, properly so called, or of roasting as popularly understood, but as one of veritable distillation. Mercury is frequently produced by simple sublimation, without the addition of flux or coal, so also is arsenic; but in most instances carbon, and such substances as decompose the ore, are added. In the mercury distillation-furnace here annexed (Fig. 1) the similarity to ordinary distillation vessels and receivers is sufficiently obvious; not very remote, either, is the similarity to the ordinary distillation apparatus shown by the Belgian furnace for zinc extraction (Fig. 2). There is no difficulty in smelting zinc under cover of carbonate of soda

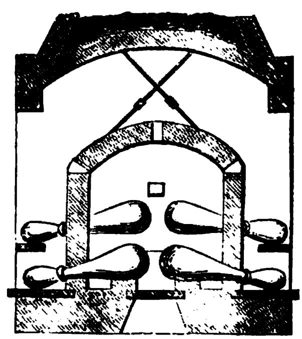


Fig. 1.

and potash with carbon, but this is an expensive flux, and, when not closely watched when fluid, the loss may exceed the value of the metal obtained. It is for these reasons found good economy to mix the zinc blende with iron; although the heat required by this process is much greater than for smelting, it is asserted that distillation is the cheaper process. The apparatus here figured is a vertical section of a furnace with its retorts, of which there are as many as twenty-two. They are placed about two inches apart from each other to admit the passage of hot gases from the furnace. The metal which condenses in these gently sloping-pipes, requires to be raked out every two hours to prevent them from being choked up, and twelve hours are required to work off a charge. Perhaps the various parts of an English zinc oven may not be quite so suggestive of a distillatory process; nevertheless they are representatives of a form of distillatory apparatus perhaps more ancient than any—a form known to the alchemists, and described by them under the name of *destillatio per descensum* (Fig. 3). A vertical section is given of this apparatus. They are sometimes round, sometimes square, having six or eight crucibles inserted in one furnace, an iron pipe inserted into the bottom of the crucible conducting the metal into a reservoir, which is filled with water.

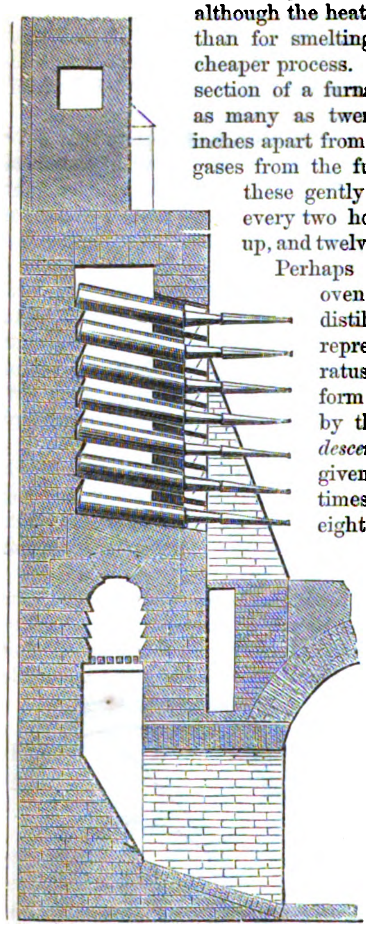


Fig. 2.

The theory of this process is very simple: the oxide of zinc mixed with carbon is reduced to metal on being ignited; and the metal, being volatile, passes in the form of vapour to the receiver, where it is condensed in the form of a crude impure metal, which requires a further process of refining before it is fit for commercial purposes.

Fluxes.—Assuming the process of roasting to have been necessary and to have been applied, and that a metallic substance still remains to be extracted from the non-volatile residue, a process of fusion must be had recourse to; it is called *smelting*. A slight chemical consideration of the materials wherewith metals are ordinarily combined, will bring to mind the fact that some are really or practically infusible. But fusion the metallurgist must have: the theoretical choice

was before him of choosing between the moist or solvative, and the dry or igneous process of effecting liquidity. He was driven by practical considerations to accept the latter; therefore fusibility is a condition so indispensable to success in his future operations that he must have it. How, then, was he to solve the problem of effecting the fusibility of things which are by their nature infusible? Chemistry renders the solution of this problem easy: there are many substances which, though infusible when heated by themselves, fuse readily enough when heated in combination; hence arises the theory of *fluxes* and *fluxing*, these terms being respectively applied to substances which impart igneous fluidity, when heated with other substances, and to the manner of using them. Silica, or silicic acid, is an infusible body when heated alone; nevertheless it fuses when sufficiently heated in contact with potash, soda, or their respective carbonates; and less readily when heated in contact with alkaline earths. Hence if the metallurgic problem were to present itself, of extracting a metal by fire from a mixture of the same with silica (chemically silicic acid), potash, or soda, or their respective carbonates, would be had recourse to in preference to all others, if considerations of profit and loss did not intervene. The price of the alkalies and carbonates of alkalies does not admit of their common application to the purposes of a flux on the large metallurgic scale; wherefore the smelter, not being able to use the flux which chemistry proclaims to be the best, contents himself with a substitute as near to the theoretic quality as may be practicable. Thus where alkalies, or carbonates of alkalies, would have been employed to facilitate igneous fusion in the laboratory, and on the small scale—probably lime, or carbonate of lime, would be employed in the larger representation of the process as performed by the metallurgist.

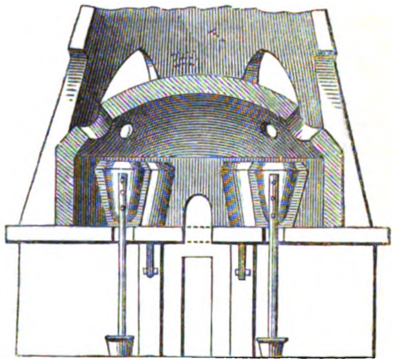


Fig. 3.

Not only do the alkalies and their carbonates perform the functions of fluxes to silicic acid, but also to several metallic oxides; amongst which those of lead, copper, and iron may be cited as familiar examples. Every person knows that flint-glass, as it is called, contains oxide of lead, that black bottle-glass contains oxide of iron—combinations which illustrate, perhaps, as well as any we could adduce, the quality of the alkalies which imparts to them the power of a flux. When it is considered that nearly all the colours which can be imparted to glass, nay, which *are* imparted to porcelain and enamel, are referable to combinations of metallic oxides with silicic acid, a still further notion will be conveyed of the extensive range of combination which may be produced by silicic acid under the influence of igneous fusion.

Next, perhaps, to potash and soda, in respect to its large range of agency as an igneous flux, comes borax. Seldom is it that the assayer in his laboratory operations on mineral ores by fire dispenses both with alkalies and with borax; but here in this case, again, considerations of expense restrict the application of this material to the laboratory, and the smelter is obliged to content himself with fluxes much lower in the scale of chemical power and efficiency. Perhaps, however, there may not be so many advantages lost from the non-employment of laboratory fluxes on the large scale as is sometimes imagined. To adopt soda, or potash, or borax, though compatible with the economical arrangements of the laboratory chemist, who will not hesitate to ruin a crucible at each operation, might still accord very ill with the economy of furnace-building. The alchemists tried to discover a fluid which should have the property of dissolving all things wherewith it might come into contact: they neglected to reflect that a necessity would arise for a vessel to keep it in. It might be thus with metallurgists on the large scale, if laboratory fluxes were cheap enough, and plentiful enough, to be adopted on the large scale.

Though the number of fluxes which the metallurgist has at his command for large operations of smelting be inconsiderable by comparison with those employed in laboratory operations, nevertheless the process of assaying is one so important to the metallurgist that every flux known to the chemist deserves his consideration. Under the subject of assaying, therefore, to be adverted to hereafter, the chemical agents will be fully discussed.

The preliminary operation of dressing having been performed on a mineral, also the further operation of roasting if necessary, the final operation of smelting naturally follows. After the general statement we have given of the nature and properties of fluxes, it will be seen that the operation of extracting metal from a metallic ore by smelting, consists in subjecting it to furnace-heat in admixture with some flux, the object of the latter being twofold; primarily to liquefy and dissolve away refuse matters, by themselves infusible; and, secondarily, in some cases to aid the decomposition, by the result of which the metal is evolved from its combinations. It remains now for the completion of our sketch of the appliances of metallurgy, that we indicate the peculiarities of the different furnaces, and the appendages by means of which the operation of smelting is effected.

Furnaces.—The various forms of furnaces admit of division into two well-marked primary classes: one class in which the material to be acted upon is brought in direct contact with fuel; the other class in which the acting fuel and the material acted upon are separated from each other.

Either of these furnaces may be supplied with air from a blast of some kind, or they may depend for their supply of air on the draught of a chimney-shaft: accordingly, in reference to these peculiarities we establish a division of furnaces into blast-furnaces and wind-furnaces. The first class of furnaces, or those in which the material and the fuel are placed in contact, differ in form and general intention, according to certain obvious peculiarities of construction. Some merely consist of a flat expansion or hearth, upon which the fuel may

either smoulder and develop a long-continued gentle heat, as in the ordinary lime-kiln; in the kiln or hearth upon which copper pyrites and copper matte are heated or roasted, and in many similar forms of hearth-furnace employed by metallurgists, chiefly to accomplish roasting operations; or the fuel may be urged to almost the highest degree of heat of which a furnace is capable, as we see exemplified in the smith's forge. A modification of this form of furnace is employed in Britain in the smelting of considerable portions of our lead ore. If, however, it be desired to raise the intensity of furnace heat to the highest point, the hearth-construction of furnace must give place to others on the type of a cylindrical or conoidal vessel. Perhaps the highest degree of furnace-heat known, is yielded by our enormous iron blast-furnaces, hereafter to be described in the treatise on iron.

Usually the aid of an artificial blast is only sought for the first division of furnaces, namely, those in which the fuel and the material to be acted upon are employed together. This, however, is by no means universal. To furnaces in which the substance acted upon does not come into contact with the fuel used, the term reverberatory furnace is applied. Amongst other metallurgic applications of this third kind of furnace, those of iron puddling and balling may be especially mentioned.

Still more important than an acquaintance with the various terms conventionally applied to furnaces, to the form of their construction, or the objects they are intended to subserve, is a full comprehension of the chemical principles upon which their efficiency depends; and with that we have to deal here. A furnace may be said to be a contrivance for giving the best practical effect to the laws of combustion as directed to some practical end. It will hence be proper that we take a casual glance at these laws, as a branch of chemical physics applied to metallurgy. All ponderable bodies are conventionally divided into combustibles and supporters of combustion; thus, for example, coal is said to be combustible, and air, or rather the oxygen contained in the air, is said to be the supporter of combustion under the usual circumstances involved in the ordinary combustion of coal. This division, though usual, is purely conventional; the function of combustion being, in point of fact, a result of chemical action betwen two agents, and appertaining to both; whence, in strict language, coal or the materials of coal and atmospheric oxygen gas are equally the subjects of combustion, and therefore combustible. Nevertheless the conventional distinction between combustibles and supporters of combustion has attained a certain significance, rendering it convenient of application in a practical sense. If we mentally review the substances of combustion they are such as most obviously present themselves to common observation. Before the employment of hydrogenous gas for heating and illuminative purposes, all popularly known combustibles presented the qualities of being visible and tangible; their combustive property was known long before the theory of combustion had been suspected, and at periods when the existence of gases was looked upon as matter to be doubted or disbelieved; no wonder, then, that the new power involved in the combustive operation was so long unsuspected, and, when discovered, allowed a subordinate place only. Though all material bodies

be impressed with the quality of ministering to the combustive function, either in the sense of a combustible or a supporter of combustion—nevertheless, the bodies which are of a nature enabling man to realise them as combustibles are few. Above all things it is necessary to the efficiency of a combustible, practically considered, that the result of its combustion shall be gaseous. When pure charcoal burns, no residue or ashes are left: the sole result of combustion is a gas, which, by reason of its nature, passes away. Even when ordinary charcoal is used, the ashes are but inconsiderable; and if coke or coal be the fuel employed, the amount of solid residue still bears but inconsiderable proportion to the mass of fuel originally used. Guided by the limiting consideration of gaseous products, it is easily seen that the only class of bodies having any claim to be regarded as combustible, in a practical sense, are two—the hydrogenous and the carbonaceous forms. All the naturally occurring fuels present us with a mixture of these; coal in all its varieties, wood, and peat, so obviously bearing out the proposition that no illustration is required. Reference to the chemical condition of carbon and of hydrogen respectively when burned will bring to mind the fact, that in proportion as hydrogen predominates, so will the combustion be more flaming; and conversely, in proportion as hydrogen is absent, so will the resulting combustion be of the incandescent or glowing kind, like that of ignited charcoal. Of late much attention has been devoted to the problem of ascertaining the comparative value of fuels. On this point some remarks will be offered in the sequel; but we may here remark that the deductions have not been attended with a corresponding amount of practical success, chiefly because of their too literal and exclusive application.

The real amount of heat capable of being developed by the given weight of a combustible by refined chemical means, is so involved with other conditions in practice as to be of itself little worth. The mechanical aggregation of any particular combustible, is at least an element of consideration of equal value to its real chemical power of evolving heat. The truth of this proposition is amply borne out by the familiar operations of coking and charcoal making. Weight for weight, coal has more combustible heat-generating matter, than coke and wood, or than the charcoal made from wood. Nevertheless, the mechanical or physical conditions of coal and wood are such, that they are totally unadapted to many of those heat-generating operations which coke and charcoal efficiently subserve. The fixedness of carbon and the volatility of hydrogen suggest the cases in which the superior absolute heat-developing power of the former would be more than compensated by the inferior localized heat-generating power of the latter. Accordingly, theory indicates, and practice confirms the indication, that in all cases wherever it is desired to bring the fuel and the material to be fused into actual contact, a non-hydrogenous fuel, such as coke and charcoal, is to be sought. When, however, the substance to be acted on is situated apart from the fuel, then the latter may, though not necessarily so, be hydrogenous. Even the carbonaceous fuels may be made to yield flame by particular treatment. If atmospheric air be supplied to the extent of ministering to the full wants of carbonaceous combustion, there

is no flame, because the carbon is immediately and entirely changed into carbonic acid; if, however, the supply of air be more scanty, or if the fuel be so arranged that the carbonic acid originally formed has to permeate white-hot carbon, it is practically deoxidized, changed into carbonic oxide, a combustible gas: hence flame ensues. So important did it seem to obtain a strongly-flaming fuel for use in the reverberatory furnace operation of iron puddling, that not merely gas-yielding bodies, but gaseous mixtures have actually been proposed, and to a limited extent carried into practice; moreover, the unconsumed inflammable gases which escape from iron-blast smelting furnaces is sometimes collected, and applied as a heating agent. Probably, however, the latter application is one in a wrong direction. It may be, and probably is true, that if an escape of combustible gas take place from one of these furnaces sufficient to be of consequence as a heat-giving agency, this circumstance suggests an imperfection in the economy of the furnace. Instead of endeavouring to collect the escaping gas to be used as a combustible therefore, it might be preferable to take measures for burning the gas while yet in the furnace, thus rendering the heat developed by its combustion effective in the furnace operation. Many English iron-manufacturers who at one time used the inflammable gases of their furnaces as a heating agent, have since abandoned the practice; and a sort of inferential testimony to the disadvantage of the process is afforded by the well-marked and ingenious effects developed in the primary operation, if the collecting of the gaseous results be made lower down in the body of the furnace than a line coincident with the termination of the first third of the vertical height of the furnace shaft. If the gases be withdrawn higher up than this, they are mixed with so much combustible material, such as nitrogen and carbonic acid, that they are worthless as heating agents; if they are withdrawn lower down, the smelting operation is prejudiced by the removal of carbonic oxide—an important agent in accomplishing the reduction of iron ore.

The subjoined table will show the composition of the gases thus withdrawn from iron furnaces in three different works, *i.e.* Veckerhagen, Clerval, and Bärum:—

	(I.). 15½ ft.		(II.) 18 ft.	
Nitrogen	62·47 —	58·115	64·28 —	63·20
Carbonic acid	3·44 —	13·76	4·27 —	12·45
Carbonic oxide	30·08 —	22·65	29·17 —	18·57
Carburetted hydrogen	2·24 —	0·00	1·23 —	1·27
Hydrogen	1·77 —	1·77	1·05 —	4·51
	100·00	100·00	100·00	100·00

Regarding the composition of the gases from Veckerhagen and the gases from Bärum (I.) and those from Clerval and Bärum (II.) as almost mutually identical, a mean may be taken in hereafter calculating their relative values. The following table represents the mean composition by volume:—

	Veckerhagen and Barum (I.) Mean.	Clerval and Barum (II.) Mean.
Nitrogen	63·4	60·7
Carbonic acid	3·9	13·1
Carbonic oxide	29·6	20·6
Carburetted hydrogen	1·7	0·6
Hydrogen	1·4	5·0
	100·00	100·00

A composition by volume which accords with the following composition by weight:—

	A.	B.
Nitrogen	63·4	59·7
Carbonic acid	5·9	19·4
Carbonic oxide	29·6	20·2
Carburetted hydrogen	1·0	0·3
Hydrogen	0·1	0·4
	100·00	100·00

The former, however, are not the only gaseous constituents which are evolved unconsumed from coal and coke-burning furnaces. Occasionally hydrogen and carburetted hydrogen are developed, as was found to be the case by Ebelmen in the gaseous evolutions of furnaces at Vienne and Port L'Eveque.

Whilst on the subject of the utilization of combustible gases which escape from iron-furnaces, it may be well to indicate that the idea first originated in 1812, at which date Abberlet obtained a patent for the application of gases thus developed, to metallurgical purposes. In 1830 an attempt was made at Holsbrücke, near Freiberg, to employ the flame of coal-gas as the source of heat for cupellation; in neither case, however, was the proposition carried out to complete success, or, indeed, fully inaugurated. The merit of accomplishing the latter is due to Faber du Faur, who, about the year 1838, tested the value of the suggestion on the furnaces of some iron-works at Würtemberg.

However doubtful the advantages may be of collecting gaseous matters from iron furnaces, and utilizing them as fuel, the prospective advantages of employing combustive gases in this way have seemed considerable enough to warrant the invention of several contrivances with this end specially in view. In France, and more especially in Silesia, combustible materials are gasefied with special reference to employment of the resulting gas in furnace operations. We have already adverted to the disadvantages which the British iron-master encounters from the necessity he is under of smelting with a fuel holding injurious quantities of sulphur, phosphorus, and some other impurities. Reflection on these conditions will indicate the advantages which should theoretically accrue from the substitution of gaseous combustibles devoid of such matters; practically, however, much cannot be said in favour of gaseous iron-smelting.

Some few years since considerable interest was excited by a patent taken out by Mr. Réece for the conversion of peat into valuable products, by a modified process of destructive distillation. One of the subsidiary propositions involved by this patent was the employment of the gaseous matters evolved to effect the smelting of iron. It was hoped that the result would be equal to Swedish charcoal wrought-iron, and that we should be rendered totally independent of that source for our supply. The process of Mr. Reece, however, has in no way answered the expectations entertained of it. One of the most powerful incentives to the employment of gaseous combustibles has arisen in countries where charcoal fuel is much used; and from the consideration of the circumstance that the mechanical conditions of powdered charcoal render it unadapted to furnace operations. Every person who has been accustomed to work with charcoal as fuel, even on the smallest scale, must have experienced the loss which arises from the pulverulent quality of that substance, and can readily imagine that this disadvantage increases when charcoal is employed on the manufacturing scale. Now the powder thus resulting, though unfit to be employed in the condition of furnace fuel, is in the best state of mechanical disaggregation to be converted into gas. Perhaps the most successful apparatus for effecting the gasification of charcoal is one used in France, and constructed on the model of an iron smelting-furnace.

It consists of a funnel or hopper into which the powdered charcoal is thrown, which latter sinks by its own weight into the body of the furnace, and is there exposed to a current of air forced upwards through it, by a blast-pipe, which enters the furnace underneath. If the hopper be kept well filled with charcoal powder, no gas will escape from its orifice; but the entire result of gasification will find exit by a tuyere, and this under considerable pressure. The apparatus in question is specially designed for the combustion of charcoal powder; lump charcoal may, however, be used if the furnace or hopper be supplied with a cover to retain the gaseous products of combustion. Independently of the mere question as to the advantages or disadvantages of gaseous combustibles abstractedly considered, the process of gas generation by the transmission of atmospheric air through burning materials is attended with collateral difficulties. If care be not taken to prevent the admission of more atmospheric air than is actually required to subserve the process of slow combustion, an explosive mixture is formed, and danger from that cause is imminent: on the other hand, if the gaseous materials be allowed to escape unconsumed, the attendant workmen are liable to be poisoned.

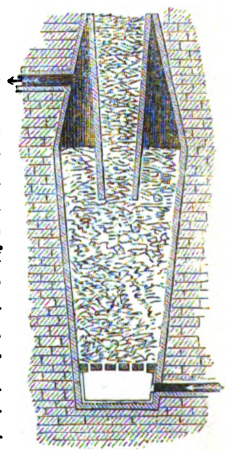


Fig. 4.

Natural and Artificial Blasts.—Next in relation to furnace-heat we have to consider the various means had recourse to for producing atmospheric currents. These admit of division into natural and mechanical; the former

comprehending the various forms of chimney draughts, the latter all those various applications of compressive means which will be presently set forth in detail. The action of chimney draughts is immediately referable to and dependent upon the circumstance that atmospheric air, like all other gases and most other bodies of whatever cohesive state, is expanded and rendered specifically lighter by heat. Thousands of examples of this result continually present themselves, from which we shall select a few prominent illustrations. An illustration of the diminution of specific gravity of a gaseous mixture is furnished by the blowing of soap-bubbles. The function of respiration causes a portion of the air taken into the lungs by the act of breathing to be robbed of its oxygen, which, by combining with the carbon of the blood, forms carbonic acid, and is in this state of combination expired. Seeing, then, that the air expired from the lungs is not pure atmospheric air, but a mixture of the latter with nitrogen, carbonic acid, and aqueous vapours, it follows that the specific gravity of the gaseous material expired is heavier (at equal temperatures) than that of the unchanged atmospheric air. Although, then, a soap-bubble, blown with warm air from the lungs, rises, this rising cannot depend on any quality of diminished specific gravity as a function of the gaseous matter wherewith they are filled, inasmuch as we have seen the latter to be specifically heavier by the amount of carbonic acid present; it depends on the circumstance that the gaseous materials are expanded by heat, owing their increased lightness to that cause. Hence it is that, although for a time the bubbles ascend, their ascension is not continuous—as would have been the case had they been filled with hydrogen gas—but only temporary: as soon as their gaseous contents become cooled to such a degree that they are specifically heavier than the external air, they descend.

An instructive toy, demonstrating the ascensive tendency of heated air, is represented in Fig. 5. A circular disc of card-board being cut, a piece of thread is attached to the centre; and being fixed to a hook, the card is suspended from a fixed support. Thus treated, the cut card unravels, and becomes a conoidal screw helix, susceptible of rotation when an upward force is applied.


Fig. 5.

If now any small source of flame be placed underneath, the helix will rotate, thus demonstrating the agency of an upward force, which evidently is that of air ascending, on account of the diminished specific gravity referable to expansion by heat. On precisely similar principles is constructed the smoke-jack, as it is called: an instrument whose rotation is totally independent of smoke, and is altogether referable to the ascensive force resulting from the expansion of atmospheric air. Manifested in a different way, though referable to the same primary cause, is the force which causes the ascent of a Mongolfier or fire-balloon.

Chimney-draught is a natural and very obvious consequence of the expan-

sion of air by heat, to which our attention has been directed. The combustible materials cannot, as is well known, burn without the contact of air. Part of the air concerned is separated into its constituents; one part of oxygen uniting with carbon to form carbonic acid, another part with hydrogen to generate water—a final portion of air remaining undecomposed, and escaping as it went in. Whatever the gaseous or vaporous constituents which escape from burning materials may be, they are heated by the fire to which they have been exposed, and are for that reason expanded; hence they have become specifically lighter, and ascend, leaving a partial vacuum in the chimney or shaft, to be made good by a further flow of atmospheric air, or, more properly speaking, the gaseous results of its decomposition. A consideration of the principles on which the draught of a chimney depends, will render manifest the fact that a chimney may be too long for the most complete activity of which a chimney is susceptible. If it be so tall that the upward currents of air have time to cool until its specific gravity becomes lower than the specific gravity of the external air, or even coincident with it, the practical, no less than the theoretical, length has been exceeded. It will be evident, moreover, that in order to obtain the maximum heat for any given fuel of which a furnace is susceptible, no more air should be allowed to permeate the burning materials than the amount absolutely necessary to promote the highest rate of combustion. Any amount of passing air in excess of this theoretical quantity, whatever it may be, acts as a cooling agent; and instead of augmenting the power of combustion, diminishes it.

All furnaces which rely on mere chimney-draught for determining the passage of atmospheric air through the materials of combustion, are under the necessity of sacrificing a portion of fuel to the object of producing the necessary flow of air; hence for the greater number of operations requiring a very intense heat, chimney-draught as a means of effecting aërial transfusion is dispensed with in favour of some form of blast. There are some purposes, however, for which the application of a blast, in the ordinary sense of the term, would be inconvenient; in which a chimney-draught must be relied upon to some extent; its power being increased by some collateral means. Iron tubular chimneys do not answer well, because of the rapidity wherewith heat is lost through this substance, and the specific gravity of the gaseous matter which they pour forth diminished. Nevertheless iron, or at least metallic, chimneys are a necessity in the case of steam-vessels and locomotive carriages. Neither one nor the other can dispense, therefore, with a powerful draught, which is accomplished by the upward pressure of a steam-jet.

The effect of this liberation is to drive a column of atmospheric air violently before it, thus compensating not alone for the cooling tendency of the materials of the chimney, but for the inadequate height to which the chimney itself is limited by the necessities of steam-ships and locomotive-carriages.

The pressure of steam applied as above-mentioned is very great. Perhaps considered as a means of air propulsion, without regard to the moisture imparted, there is no method of producing a blast equally effective. Necessarily,

however, the steam must impart moisture to the air, thereby deteriorating the latter for all combustive operations.

Blast-Machines.—The most primitive method of generating an air-blast is by some modification of the leather bellows. Originally bellows were nothing more than the skin of an animal closely sewn except at one part, to which a spout or delivery-tube was attached, also serving to admit a further charge of air when the sides of the bag were pulled asunder. From this primitive instrument to the valved single bellows, and thence to the valved double bellows, used at this time by blacksmiths, and yielding an uninterrupted stream, the transition is obvious. The great advantages of bellows are economy of first cost and facility of employment: they serve perfectly well for blacksmiths' forges and small furnaces; but the use of bellows in metallurgic operations on the large scale is limited, and gradually decreasing.

The blowing apparatus now generally employed on the large scale is that of compression cylinders. It is obvious that a metallic cylinder, like the cylinder of a steam-engine, may be converted by a simple arrangement of valves and piston work into a powerful apparatus for delivering compressed air. An usual form of compression cylinder is represented below.

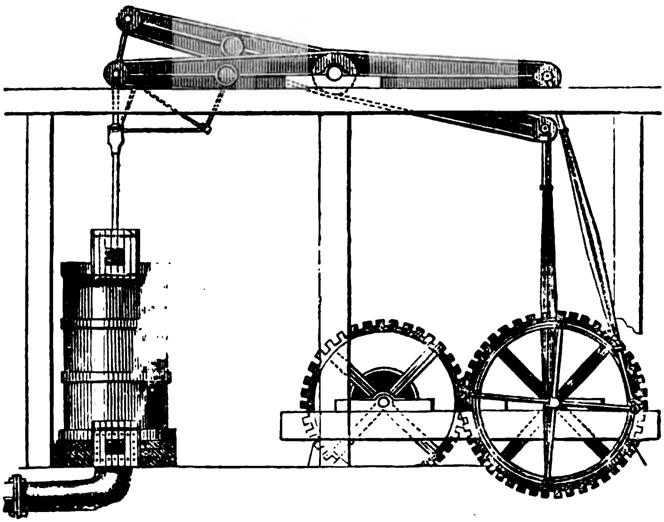


Fig. 6.

The effective power of a blowing cylinder—or, in other words, the quantity of air of specified density which it contributes in a given time, may be arrived at in two distinct ways. The first consists in ascertaining the actual capability of the cylinder, and determining the number of times it can be filled with air and the air discharged in a given time. The second method is by ascertaining the velocity or power of the first, determined by taking into con-

sideration the circumstances of barometric pressure, moisture, and temperature at the time of the experiment.

As regards the former method of investigation, it must be borne in mind, that the number of times per minute, or for any other given period, that a blowing cylinder is filled, would be a very false criterion of the actual amount of air which finds its way into the furnace. Owing to the elasticity of the air, ineffective space in the cylinder, loss of air between the cylinder and piston, added to further losses in the windways and regulators, the actual amount of air which finds its way into the furnace is always some 20 or even 25 per cent. less than the total amount subjected to compression. This loss occurs even in the best blowing cylinders; in wooden blowing-chests—a common form of apparatus—the loss not unfrequently amounts to nearly double. Being aware of the loss incurred, the appended formula may prove serviceable. It teaches the amount of air of natural atmospheric density taken into a blowing cylinder in one minute of time.

$$Q = \frac{g^2 . \pi . h}{4} . \frac{60}{d} . 4$$

in which

Q represents the amount of atmospheric air sought—in cubic feet.

g the diameter of the piston in feet.

π ratio of circumference to diameter (*i.e.* the number 3.1515).

h length of piston-stroke expressed in feet.

d number of revolutions expressed in terms of seconds.

Though compression-cylinders furnish the most powerful and the most

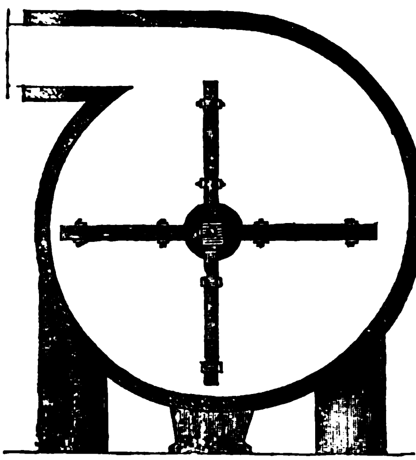


Fig. 7.

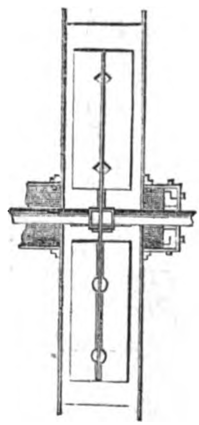


Fig. 8.

certain means of delivering air in a blast, there are others of great practical importance. The ventilator or fan-blast is one of the most useful, and at the

same time most simple; it is represented in the two preceding diagrams sectionally. Fig. 7 represents a cylinder or drum, cut transversely to its axis, and displaying the sectional view of four vanes. Fig. 8 represents the same cylinder cut parallel to its axis, and displaying two central openings, one on each side.

When the vane is put in motion, air enters by the central apertures, and is forcibly and continuously driven out through the aperture, thus constituting the blast. This form of apparatus has been so familiarized by being substituted for domestic bellows, that its description is almost unnecessary.

Notwithstanding the disadvantages, practical no less than theoretical, which attach to the employment of moist air in furnace operations, hydraulic blasts of simple description are amongst the most ancient; whilst modern variations on the principle of hydraulic blowing have given rise to some simple and curious machines.

The trompe, as it is called, is a simple and ingenious method of determining a current of wind by a falling current of water. It is a form of apparatus very prevalent in Catalonia; hence the appellation "Catalan trompe," which is sometimes applied to it. The instrument, however, slightly modified, is employed in Italy and Switzerland, being applicable to mountainous regions where high falls of water can be commanded, and the amount of atmospheric pressure required is inconsiderable.

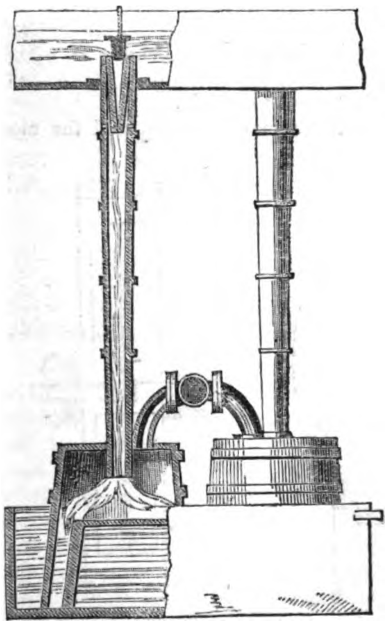


Fig. 9.

An examination of the accompanying figure will render evident the construction and principles on which the trompe is founded.

The diagram (Fig. 9) represents a cistern above, containing water, and communicating with the vertical pipes which respectively terminate in two chests. Between these chests, and placing them in aërial connection, is a semicircular pipe; and the part of the apparatus on the left, sectionally represented, shows a transverse plank, on which the water is broken in its fall. The action of the trompe is this:—The vertical column of water, in its descent, carries before it, and mingled with it, considerable portions of atmospheric air: striking against the transverse plank, a separation between the air and water is effected,—the former passing into the arched tube, and escaping as a blast

through a tabular orifice corresponding with O, whilst the water passes into the lower reservoir. This form of apparatus would be quite inoperative if applied to furnaces heated with coke or coal; but it answers sufficiently well in cases where charcoal is the fuel employed.

Chain Blast.—This is a somewhat elaborate application of hydraulic laws to the purpose of creating an air-blast. It is depicted in the accompanying diagram (Fig. 10), and its construction is as follows:—An endless chain, furnished with certain appendages, the motive of which we shall presently explain, is seen to pass over a wheel or pulley, and through a pipe which terminates in an air-chamber below. This air-chamber communicates with a bent tube, as represented: and a lateral tube pointing towards the left is also seen to be connected with the upper part of the vertical tubular shaft. Glancing, now, at the transverse appendages to the endless chain, placed at regular intervals throughout its length, they consist of cylindrical boxes quite open at one end, and capable of being opened or shut at the other end, each by two flaps or valves. The latter fall by their own weight when the cylinders are on the left, or, as will be hereafter seen, at every part of their downward descent, and open (as represented in the diagram) when moving upwards. When it is now explained that water enters by the lateral orifice *f*, the action of the machine will be made evident. The water pressing successively on each cylinder, causes it to descend through the vertical pipe, conveying with it the air with which it is filled, and which cannot escape, because the valves are shut; each cylinder, therefore, liberates its contents of air into the air-chamber below, and thence through the associated blast-tube. Passingon, the valve side of each cylinder again looks downwards, and the valves open, only to shut once more, and to act as before described, so soon as they again take their downward course.

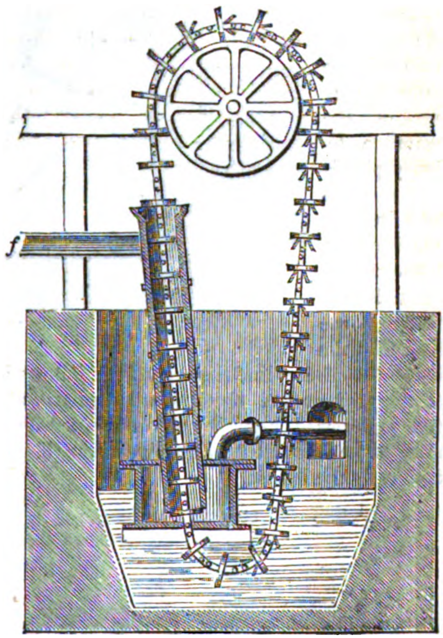


Fig. 10.

A still more powerful and not less ingenious method of creating a hydrostatic blast, is furnished by the machine known on the Continent by the

name of "*Cagniardelle.*" This instrument may be generally described as consisting of a cylindrical screw, the shaft of which fits air-tight to a cylinder in which it is inclosed,—the cylinder being diagonally placed in a reservoir partially filled with water (Fig. 11).

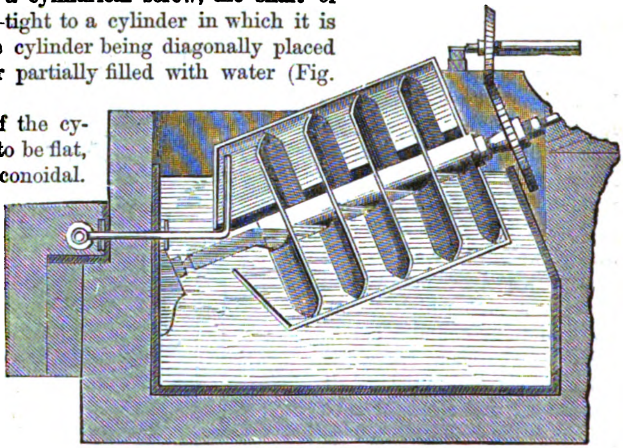


Fig. 11.

One end of the cylinder is seen to be flat, the other conoidal. Through the truncated apex of the conoid a delivery pipe is also seen to pass; but the diagram does not represent what is actually the fact, that the flat end of the cylinder is open. It follows as a necessity of the construction of this instrument, that the atmospheric air which enters by the open flat end is screwed along by the combined force of rotation and water-pressure until it reaches the tube passing through the truncated apex, which tube is a delivery tube for air.

CHAPTER III.

ON THE VARIETIES AND COMPARATIVE VALUE OF FUEL.

We come, now, to the consideration of a very important matter in relation to metallurgy, the consideration of the various kinds of fuel employed by metallurgists; and the special peculiarities, advantages, and disadvantages of each. Collaterally, we have already had reason to remark that hydrogen and carbon may be regarded as the only materials of fuel practically considered; we have shown that hydrogen is the greater heat-developer of the two, but that carbon has the larger sphere of utilization. Collaterally, too, we have had occasion to go somewhat into detail concerning the substitution of combustive gases; whence, therefore, the remarks we now propose to offer will be limited to the consideration of solid fuel, both natural and artificial.

Division of Fuels.—Conventionally, fuels admit of division into vegetable and mineral—understanding by the latter designation, coal in all its varieties, and coke the derivative of coal. We might add, were it of sufficient importance, the third class of animal fuel, inasmuch as animal matters, fat especially, have been employed in the formation of at least one kind of artificial fuel.

Under the head of vegetable fuel, we understand wood and wood-charcoal, and peat. The former has a very limited application to the processes of metallurgy, but the latter is in some parts of the world a fuel of great importance: it was of great importance in our own Isles some centuries back; and it would continue to be so now if a greater supply of it were procurable. A great disadvantage consequent on the use of wood as fuel, is the obstinacy with which it absorbs and retains water. Even timber which has been barked and felled for twelve months, will be found to contain on the average somewhere about 25 per cent. of water. This circumstance, added to the hydrogenous composition of wood, giving rise to a flame beyond the wants of the smelter, has led to the abandonment of wood as furnace fuel, even in those parts of the world where wood is most abundant. It is now almost universally charred by the metallurgist before being employed in his furnace operations.

The processes by which wood-charcoal is made, resolve themselves functionally into two, although the appliances had recourse to for this purpose are various. Either the wood is exposed to smouldering heat, with as little exposure to air as may be consistent with the support of slow combustion, and all the volatile materials evolved are lost; or the wood is submitted to a process of destructive distillation in retorts, whereby not only is charcoal of better quality produced, but acetic acid, tar, and other organic volatile products of different degrees of value, are set free and collected. A third process of charcoal manufacture may be indicated: it is the process of M. Violette, which consists in the injection of high-pressure steam into cylinders, holding blocks of dried wood; which by exposure in this manner to the steam become

charred. Inasmuch, however, as this process of charcoal manufacture is never adopted for metallurgic ends, but for the production of a superior kind of charcoal to be employed in the manufacture of gunpowder, any further description of the process in question is here unnecessary.

Peat.—The substance known as peat or turf, occurs enormously developed in various parts of the world, especially in the northern hemisphere. Inland portions of North Holland and Germany are conspicuous as peat-yielding localities. The extensive domestic applications of peat-fuel by the Dutch must have been conspicuous to every one who has been in Holland; and at home, both Ireland and Scotland are largely indebted to peat. Peat, chemically considered, may be regarded as a fuel something between wood and wood-charcoal, differing from both, however, in yielding a greater amount of ashes. This peculiarity can easily be accounted for: peat during its existence in masses becomes infiltrated with water holding mineral salts,—the water evaporating, leaves the salts behind as a fixed residue, to appear as ashes when the peat is burned.

Moreover, finely comminuted particles of mould get infiltrated into the interstices of the peat, in this way also increasing the amount of resulting ashes. The amount of ashes, however, yielded by peat in different localities, varies within wide limits, some specimens yielding not more than one-third part per cent., whilst the ashes of other varieties amount to upwards of 30 per cent. When analyzed, these ashes are found to contain abundance of phosphates and sulphates; but, what is extraordinary, no alkaline carbonates, as is the case in the ashes of all wood.

As respects the distribution and prevalence of peat, it has been calculated that it constitutes no less than one-seventh of the surface of all Ireland, or two million eight hundred thousand statute acres. The average thickness of the Dutch peat formations have been estimated at two feet; in Ireland, however, the depth of peat bog is usually much greater—sometimes no less than thirty feet.

The vegetables of which peat is formed differ, as will have been anticipated, for different regions and climates. The chief vegetables which have contributed to the formation of peat in the northern hemisphere are mosses, amongst which the *Sphagnum palustre* especially predominates; heaths, and rushes; fuci and reeds, and one or more species of cotton-grass. Besides these there are frequently discovered in peat-bogs large trees of various kinds, and occasionally the remains of animals. The chemical agency of peat is inimical to organic decay, probably on account of the tannic acid contained by it. This is the explanation of the unchanged state of animal remains frequently discovered in peat. Amongst the most frequent of these animal debris is a sort of fat, to which the appellation "peat-fat" has been given; it is probably the result of soft animal tissues, converted into the ammoniacal soap known as "adipocere." The deeper layers of peat bogs are very ancient; nevertheless, unlike coal, peat is undergoing formation even now. In the southern hemisphere peat occurs, but its presence is demarcated by the 45th degree of latitude. Peat of the southern hemisphere is made up of the partially decomposed

substances of nearly every vegetable species now growing in the localities where it is found. The preparation of peat for fuel differs in different localities in these isles, where, ~~on account~~ of the abundance of coal, peat is of very little importance. The usual operation of ~~preparing~~ it for fuel merely consists in cutting it out of the ground by spade labour in pieces of suitable dimensions, and drying them in stacks. In Germany a similar process of preparation is adopted; but in Holland the process is more elaborate; this being chiefly necessary on account of the less coherent state in which the Dutch peat is found. It is here infiltrated with water—more *mud-like* than the peat of Ireland or Germany; it does not therefore admit of being merely spaded out and dried, but is extracted by a sort of cullender or ladle as a kind of mud; which, being placed in suitable receptacles of equal depth throughout, is submitted to pressure until the greater amount of water which it contained is expelled. One great disadvantage of peat, considered as furnace fuel, is its great porosity; to the end of diminishing which, the operation has been proposed, and to some extent carried into execution, of submitting it to hydrostatic pressure, and giving it the form of coherent blocks. Considered without reference to expense, the treatment succeeds; but a review of the stages of the operation involved, demonstrates it to be costly. Peat charcoal is still more difficult to be managed as a fuel than peat itself. When charred, peat does not yield lumps like wood, but falls to powder. Lately, peat charcoal has been recommended as a deodoriser, and as a manure; but the only way hitherto devised of converting it into a practicable fuel consists in mixing it with tarry matter and moulding it into blocks.

Coal.—We need scarcely enlarge on the chemical nature of this important variety of fuel. Every person knows that coal, of whatever kind, originally consisted of vegetable growths deposited, in some manner not easily understood, at various epochs of the world's geological history, and subjected to the chemical changes, under various degrees of pressure, which have resulted in a conversion of the original wood into one or other of the varieties of coal which are now found. As regards the methods by which the vegetable growths were first deposited, there are two hypotheses, both perhaps correct, each applicable to different carboniferous regions. According to the assumptions of one hypothesis, the vegetables out of which coal has been subsequently formed, grew in the localities where the coal is now found, and were submerged by some geological convulsion; according to the other hypothesis, the vegetable growths were of the nature of drifts, having been wafted down by rivers, and deposited in their deltas; subsequently these deltas in question having become dry land, the vegetable matter was left in the position where we now find it as coal. There is reason to suppose that every coal formation was originally basin-like; and as we have frequently seen in many carboniferous localities the basin form is disturbed, broken, and interrupted, it is probable that these changes are referable to geological disturbances of the earth's crust.

Coal is found in three distinct geological formations, though in quantities so unequal, and of kinds so different in quality and importance, that the dis-

tinctive geological appellation of coal-measures or coal-formations is amply justified. The coal-measures are found overlaying the old red sandstone, and present the two well-marked varieties of anthracite, which is lowest down, and brown coal, which occurs in layers above. Anthracite is the oldest of all coal-formations, and it has been subjected to the greatest amount of chemical agency, to which the nature of its composition and the mode of its combustion amply testify. Anthracite partakes much of the nature of charcoal. It is almost devoid of hydrogen or hydrogenous components; for which reason it yields little flame during combustion, and is therefore frequently selected when flame and smoke are undesirable. The foregoing constitute what are termed the coal-formations. They are incomparably of greater importance than any other, both as regards the amount of coal yielded and its adaptability to the wants of mankind.

Coal of the secondary formation occurs in the older members of the new red-sandstone series, especially in the oolitic strata. In the tertiary formations, it occurs in fresh-water limestone strata, and a few other members. Lignite and Bovey-coal are referable to this last, both characterised by the incipient change, by comparison with other coal, which the vegetable matter yielding it has undergone.

The use of pit-coal (by which is to be understood coal of the carboniferous series) is stated to have been first commenced in Britain in the ninth century. In 1269, Henry permitted the inhabitants of Newcastle to dig for coal, from which period it gradually, though very slowly, found its way into ordinary use; not travelling far, however, from the locality of its production.

The employment of coal as a fuel in London, only dates from about two hundred and fifty years ago, when, and for a long time subsequent, two small ships were found to be sufficient for supplying metropolitan wants. A prejudice, indeed, long existed against the employment of coal in London. The two small ship-loads could not, when distributed through all London and burned, have given rise to an insufferable amount of smoke, one might be inclined to think; nevertheless, Londoners, more fastidious apparently then, in the matter of smoke, than now, called pit-coal "a nuisance." Sovereigns, even, tolerated it only; and though the use of coal was ordinarily permitted in London, yet a statute passed in the reign of Edward I., and one subsequently in the reign of Elizabeth, prohibited the burning of coal in London during the sittings of Parliament, lest British law-makers should be incommoded by the smoke therefrom arising. At a subsequent period, somewhere about the year 1649, a prohibition was not only laid against the use of coal in London, but the prohibition included another nuisance which modern Englishmen would be slow to admit in that category,—the second nuisance being no other than "hops." In the year 1520, Newcastle coal was first imported into Paris; but the inhabitants of the French capital have not, even now, taken cordially to the use of coal. The working of the Scotch coal-pits was commenced in 1231, a period, therefore, somewhat later than the first discovery of Engligh coal. In Belgium, coal was not extracted until about the year 1198 or 1230,—the place of extraction being Liege.

The coals annually raised in Great Britain have been estimated at not less than 35,000,000 of tons, of which not more than 3,000,000 are exported,—leaving for home consumption 32,000,000 tons of various kinds. Nearly 3,500,000 tons of this quantity are annually consumed in London! Of iron we raised in 1750 only 30,000 tons; by 1850 the quantity had increased to 2,250,000 tons. According to the official returns of 1849, the export of iron of all kinds was valued at £4,500,000.

Artificial Fuel.—The term artificial fuel has been applied to signify various combinations of combustible matters, either of which alone would present mechanical or chemical conditions unfavourable to combustion for practical appliances. The first attempt at the manufacture of this kind of fuel appears to have been undertaken in Norway, where the sawing of large quantities of timber gives rise to a quantity of sawdust, not adapted to the purposes of fuel in its original state, but which, nevertheless, contains similar elements of combustion with wood itself. Accordingly, the sawdust was mingled with tar; and being pressed into blocks, these were applied to furnace operations.

We in these isles have not a sufficient accumulation of sawdust to render its employment as fuel a desideratum; a remark which equally applies to Germany. Both ourselves and the Germans, however, have enormous magazines of turf, and wasteful debris of small coal, both of which it would be desirable to convert into the mechanical shape and condition subservient to good combustion. Accordingly, numerous kinds of artificial fuel, consisting of burning turf, turf-charcoal, and small coal, have been prepared, with various degrees of success. Swazil, an Austrian, combines porous turf with organic matter, induces a peculiar state of decomposition between the two, and generates, it has been said, an effective artificial fuel. Hill, a British chemical manufacturer, first submits turf to destructive distillation, thus liberating tarry products, which he subsequently incorporates with the charcoal left behind, and, by pressing the compound result into blocks, in this manner prepares his fuel. Another inventor, a foreigner, mixes small coal with fat, and presses the result of the mixture into blocks. Warlich mixes small coal with alum or salt, forms the mass into blocks, and exposes them to destructive distillation in a retort. Bessemer's process of artificial fuel manufacture is based upon the circumstance that small coal, when heated to about 500° or 600°, becomes pasty, and agglomerates. Such are the chief varieties of artificial fuel—neither of which is so much a desideratum with smelters, as applicable to the purposes of steam-ships; while condensation of combustible matter and the facility of stowage, dependent on regularity of form in the masses, are matters of especial consequence.

Comparative Value of Fuel.—Pyrometrically deduced, this is a most important subject of inquiry to the metallurgist, and it is one beset with many difficulties. We shall indicate the principal methods of calorific estimation which have been devised, repeating, however, the observation already made, that for practical operations the mechanical structure of a fuel is a consideration of almost equal importance with its chemical nature.

Inasmuch as there is no absolute or naturally existing want of heat, the philosopher, in prosecuting his researches in this field, is limited to the consideration of the amount of heat by which a given quantity of one combustible exceeds the amount yielded by the same quantity of another. In making this comparison, we may compare equal weights, or equal measures; if the former, we arrive at the absolute—if the latter, we deduce the relative effects of heat. Firstly, we shall review the principal methods which have been devised for acquiring a knowledge of the absolute effects of heat. And first, by the method proposed by Rumford—premising that, in expressing calorific effects in thermometric degrees, the Centigrade scale will be adopted, as affording greater facilities of calculation than the scale of Fahrenheit.

Rumford's method of estimating the absolute effects of heat developed by a fuel consists in determining the quantity of such fuel necessary for heating a given weight of water from 0° to 100° C. According to this mode of investigation, it is found that, respectively, equal weights of hydrogen, pure carbon, and wood-charcoal heat water from 0° C. to 100° C. in the following ratio:—

PARTS BY WEIGHT.

1 . . .	Hydrogen—heat .	236 parts of	water from 0° C. to 100° C.
1 . . .	Carbon " .	78 "	
1 . . .	Wood Charcoal " .	75 "	

Reflecting now that the number of degrees in the Centigrade scale between 0° C. and the boiling point of water is 100, it follows that the respective figures of absolute heating power for each degree, and for each of the bodies respectively above-mentioned, may be deduced by multiplying the parts by weight of water heated from 0° C. to 100° C. by 100: whence it follows that

PARTS BY WEIGHT.

1 .	Hydrogen—heat . .	23600 parts of	water from 0° C. to 100° C.
1 .	Carbon " . .	7800 "	
1 .	Wood-charcoal " . .	7500 "	

Thus we deduce what may be termed the respective unities of heating effect for hydrogen, carbon (pure), and wood-charcoal. Furthermore, the above relations admit of simplification. Natural unit of absolute heat, we have already mentioned, there is none. It will be desirable, therefore, to assume a conventional or empirical standard; and carbon being, *par excellence*, *the* combustible involved in technical operations based upon combustion, the substance may be taken as the conventional unit. Dividing, therefore, the first and the last of the numbers given in the preceding series, by the middle number, *i.e.* 7800, as that indicating the unit of absolute heating effect for carbon, we then make carbon the prime standard or unity, representing its absolute heating effect by 1, and the respective absolute heating effects of hydrogen and wood-charcoal as represented by the following series:—

Carbon . . .	= 1
Hydrogen . . .	= 3.03
Wood-charcoal . .	= 0.96

From this statement the deduction is arrived at, that the more hydrogenous a fuel is, the greater the absolute heating effects resulting from its combustion.

Next, we shall consider the process devised by Karmarsch for obtaining similar information. Instead of measuring the absolute heating power of a combustible by ascertaining the weight of water it was capable of heating from 0° C. to 100°, Karmarsch ascertained the weight of water which a given weight of fuel during combustion could raise in steam. This was the process followed by Brix, in determining the relative value of Prussian fuels. It is, perhaps, unnecessary to indicate, that, to arrive at the greatest correctness of which the process is susceptible, the water used in the series of comparative experiments must be taken at the same temperature. Brix, in conducting his investigations, used water of 0° C. or 32° F.: his scientific expressions were, moreover, conveyed in terms of the Reaumur thermometric scale.

Berthier's method is more complex. It is based upon atomic, or (to avoid the language of theory) equivalent proportional considerations, which the following remarks will, it is presumed, make evident. Inasmuch as the equivalent weights of hydrogen, carbon, and oxygen, are respectively 1, 6, and 8, and the respective compositions of water and carbonic acid are

	Oxy.	Hyd.		Oxy.	Hyd.
Water (parts by weight or equiv.) . .	8	1	or	16	2
	Oxy.	Car.		Oxy	Car.
Carbonic acid („ „) . .	16	6	or	16	6

it appears that two parts by weight of hydrogen, in generating water by combustion with oxygen, consume sixteen parts of the latter; whereas the same quantity of oxygen (*i.e.* sixteen parts by weight) is only consumed by six parts of carbon, in becoming carbonic acid. Hence the deduction follows, that a given weight of hydrogen in forming water by combustion, unites with three times as much oxygen as an equal weight of carbon during the combustion of the latter, and the formation of carbonic acid. Now, the fact has already been proved as a result of Rumford's mode of experimenting, that the relative amount of absolute heat developed, as between hydrogen and carbon, is as 3 to 1; whence it clearly follows, that the absolute heating effects of carbon and hydrogen are in direct proportion to their combustive capacity of absorbing oxygen: a deduction, indeed, first promulgated by Welter, and which—though since his time it has undergone modifications—is still reliable. Berthier expressed the absolute heating effects of any given combustible, in terms of the weight of oxygen consumed, by a given weight of the combustible during the progress of its combustion. This was practically effected by heating the combustible in contact with oxide of lead. It follows that, in proportion to the quantity of oxygen taken away, so would be the weight of lead reduced to the metallic condition; and this latter being collected and weighed, the absolute heating effects of the combustible were expressed fractionally by the weight of oxygen consumed, but directly in terms of the lead reduced. In this way he found that,

1 part of pure carbon gave . . 34 parts of lead.
1 part of pure hydrogen gave . 104 „ „ „

If it be now assumed that any particular combustible under examination should be in relation to a mass of lead, the weight of which is m, then the ratio between the absolute heating effect of the combustible in question, as compared with that of pure carbon, will be expressed by the fraction $= \frac{34}{m}$, and the statement for this absolute heating effect expressed in units of heat will be

$$= 78.100 \cdot \frac{m}{34} = 230.m$$

Though somewhat complex in theory, the process just described is conducted with facility. The results are tolerably reliable; but they involve a constant error of about $\frac{1}{8}$th. Forchammer has somewhat improved this process, but the results still involve a constant error.

The chemical reader will perceive that the process of Berthier just described is very nearly allied to the ordinary combustive operations followed in organic analysis. If, instead of oxide of lead, oxide of copper be employed, we have at once the preliminary conditions of ultimate organic analysis. Accordingly, this means of estimating the absolute heating effect of fuel has been frequently adopted,—the oxygen appropriated by combustion being calculated in the usual manner from the amount of carbonic acid and water respectively developed, and the final reduction into terms of absolute heat being deduced from the application of Welter's laws, explained in page 47.

Besides the methods already indicated, may be noticed the process described by Sheerer in his *Metallurgie*, vol. i. p. 139, founded on consideration of the chemical composition of the fuel. In addition to which, processes have been devised with the same object in view, by Laplace, Lavoisier, Dalton, Marcus Bull, and others.

Specific Heating Effects of Fuel.—We have already explained that if fuels be compared as regards the respective thermic effects of their combustion, weight for weight, the respective absolute heating effects of each will be deduced; whereas if they be compared, bulk for bulk, then we arrive at the specific heating effects of each. We arrive, therefore, at the following deduction:—Knowing the absolute heating effect of any combustible, we arrive at the knowledge of its specific heating effect by multiplying the numerical exponent of the former by the number expressing the specific gravity of the combustible.

Such, then, are the indications of theory and the results of laboratory operations thereupon founded. The practical smelter need not be told that not even a near approach to the figures arrived at is possible on the large scale. Such accordance between theory and practice could only result if the total amount of heat generated by the combustion of a fuel were concentrated on the ore submitted to its agency. This is an impossible condition; even more heat invariably escapes from furnaces in the state of combustible gas and as radiant heat, than the actual amount of heat made effective. Much may be accomplished in lessening the divergency between theory and prac-

tice by drying the fuel, as much as circumstances will permit; by regulating the amount of air-draught, applying the hot gaseous products of furnace-combustion to subsidiary purposes, and taking advantage of other conditions which, though they vary in different establishments and for different metallurgic operations, depend on a few unvarying scientific principles, and will readily suggest themselves to an intelligent observer.

Pyrometric Effects of Different Fuels.—The amount of heat evolved by any given fuel, whether in relation to its weight or its bulk, differs widely from the degree of heat capable of being yielded by it in any one locality. Varying the conditions involved a little (though not fundamentally) by assuming a parallel case, evidently a quart of boiling water contains twice the amount of heat which a pint of boiling water, though the contents of each will cause the thermometric column to stand at 212° F. Now 212° F. is, therefore, said to be the thermometric heat of boiling water; and if a thermometer could be procured capable of indicating furnace heats, we should arrive at deductions parallel with that obtained from the consideration of boiling water. For the estimation of combustive heat, however, special methods must be had recourse to; inasmuch as thermometers are not competent to indicate temperature of such high degree. The deductions are arrived at, either directly by the aid of instruments (pyrometers), or indirectly by calculation.

It is evident that the principle of expansion of liquids in tubes is unadapted to pyrometric construction, inasmuch as the utmost limit of the indication of such instruments can only fall somewhere within the boiling point of the liquid employed. Gaseous and solid bodies are, therefore, alone adapted to the construction of pyrometers.

Pyrometric estimations admit of division into three general classes: (A) those the indications of which are based upon the expansion of some particular body (pyrometer); (B) those which are founded on a consideration of the heat imparted to water by a heated body; and (C) those the results of which are deduced from considerations of the melting points of metals and metallic alloys.

(A.) **Pyrometers.**—In the year 1782, Wedgwood invented the pyrometer which has since borne his name. Its agency depends on the contraction of clay experienced when exposed to high temperatures. A cylinder of clay of some definite size when cold, which shrinks before heating to a known extent between two converging sides of a wedge-shaped cavity, sinks lower down in the same cavity after having been heated; and Wedgwood assumed that the amount of contraction of the clay would be always proportionate to the degree of heat to which it might have been exposed. This, however, is a false assumption: a long-continued and moderated heat is found, in practice, to cause an equal amount of contraction, or shrinking, with a more violent degree of heat during a shorter period; hence it follows that the indications of this instrument are all but worthless.

Daniell, Guyton Morveau, Neumann, Peterson, and Gibbon, and some others, have devised each respectively a pyrometer, the general principles

of which are alike, being dependent on the expansion of a platinum bar. Daniell's instrument is the most perfect of these, and its indications most to be relied upon: however, its use is attended with inconvenience, and it has no pretensions to the accuracy of a thermometer. In the construction of this instrument the scale-point is retained separate from the expansive platinum bar, which latter is alone exposed to heat. It is a very inconvenient circumstance attending the employment of this instrument that no indications of temperature can be gained by it whilst it remains in the furnace. The fire must be first extinguished, and the platinum bar withdrawn. Moreover, the arrangement by which the expansion of the bar is worked upon in the furnace is somewhat imperfect, and begets error.

The air pyrometer was first devised by Schmidt, in 1804, and subsequently perfected by Petersen and Pouillet. It is only a modification of the following lecture demonstration of the expansibility of air and other gases by heat.

Let a glass tube be closed at one end, and blown into a bulb, the other end remaining open. Let now the *whole* of the tube and a portion of the bulb be charged with fluid (water or mercury). This being done, let the orifice of the tube be immersed in a vessel of water. Assuming that these instructions have been strictly followed, the level of the fluid in the tube will continue to sink until all the fluid has at length been driven out of the tube, if the bulbular portion of the apparatus be heated. This result obviously depends on the expansion of the air contained within the bulb; and by noting the amount of expansion, as expressed by the descent of the fluid level, we arrive at thermoscopic indications. The material glass is obviously unadapted for resisting high degrees of heat; but if the bulbular, and a portion of the tubular part of the apparatus be made of platinum, there should result a modified instrument, capable of measuring any temperature which the metal platinum is able to resist without fusion. The common air thermometer thus modified becomes the pyrometer of Schmidt, Petersen, and Pouillet.

The final indications of this kind of pyrometer will of course be arrived at by considering the laws of gaseous expansion and the agency of heat. According to the researches of M. Regnault, the amount of expansion of atmospheric air heated from 32° F. to 212° F. is ·3665 or ·3670 on its original bulk at 32° F., being $\frac{11}{30}$ths for each degree of the Centigrade scale, or $\frac{1}{491 \cdot 13}$ for a degree of Fahrenheit.

(B.) *Pyrometers founded on considerations of the Heat imparted to Water by a heated body.*

This principle of pyrometric measurement was first adopted by Clement, Desormes, and Schwartz. It has been subsequently improved upon by Wilson.

The method of Schwartz is based upon a consideration of the formula:

$$x = \frac{Q.t'}{P + s} + t$$

in which x being the temperature sought, Q is the weight of water, the temperature of which is t' previous to the immersion of a heated body, P the weight of metal, s its specific heat, and t the temperature of water after the immersion of the heated body. Such is the principle on which the heat estimation by the foregoing process is deduced. To expatiate on it further would lead us too far from the immediate objects of this introduction.

Heat Effects Deduced without Instruments.—This method has been elaborately explained by Scheerer in his treatise on Metallurgy. Brendel, Reich, Winkler, and Merbach have also examined its conditions during investigations in which they were concerned, to determine the heating power of fuel, with especial reference to the economic application of heated air and steam.

The process admits of being generally stated as consisting in the application of formulæ representing the absolute heating effects, the relative weight, and specific heat of the products of combustion evolved from the fuel under examination. The following case will serve as an example of the nature of the process, and its application to the combustibles carbon, hydrogen, and carburetted hydrogen. Equal weights of the three respectively are of course marked.

		Centigrade.
Carbon burned in oxygen to form carbonic acid, yields heat		= 9873°
Do. burned in air ,, ,,	,,	= 2458
Carbon burned in air, and forming carbonic acid	,,	= 1310
Carbonic oxide gas burned in air	,,	= 2121
Do. do. burned in oxygen	,,	= 5316
Light carburetted hydrogen burned in air	,,	= 2290
Do. do. burned in oxygen	,,	= 6308
Olefiant gas burned in air	,,	= 1935
Do. burned in oxygen	,,	= 4766
Hydrogen burned in air	,,	= 2080
Do. burned in oxygen	,,	= 4073

From a consideration of which numerical exponents it is evident that the combustibles under consideration evolve, during combustion, an amount of pyrometric heat, or furnace-heating power, in direct proportion to the carbon which they contain; whilst the total or absolute heating effects are proportionate directly to the quantity of hydrogen: the latter condition is referable to the circumstance, that the water resulting from hydrogenous combustion absorbs, and renders latent, nearly four times as much heat as the carbonic acid resulting from the burning of carbonaceous materials.

Tabulating the results of Scheerer's experiments, we arrive at the following expositions by weight and by measure:—

I.—By Weight.

One part by Weight of each of the following requires for Combustion.	Parts by Weight of Oxygen.		Carbonic oxide.	Carbonic acid.	Water.
Carbon	2·67	To generate respectively	—	3·67	—
Carbon	1·33		2·33	—	—
Carbonic oxide	0·57		—	1·57	—
Light carburetted hydrogen	3·43		—	3·14	1·22
Olefiant gas	4·00		—	2·75	2·25
Hydrogen	8·30		—	—	9·00

II.—By Measure.

One part by Measure (volume) of each of the following requires for Combustion.	Parts by Measure of Oxygen.		Carbonic acid.	Water.
Carbonic oxide	0·5	To generate respectively	1	—
Hydrogen	0·5		—	1
Light carburetted hydrogen	2		1	2
Olefiant gas	3		2	2

Such, then, is the exposition of Scheerer's ingenious process. The theory on which it is based is unimpeachable; and though its results are those of maximum effects, practice, nevertheless, can closely approach them under favourable circumstances.

(C.) *Pyrometric estimations deduced from a consideration of the Melting Point of Metals and Metallic Alloys.*

The first proposition to estimate the degree of furnace heat by this means originated with James Prinsep in 1827; more recently it has been carried into execution by Plattner. The following considerations will, it is presumed, render evident the nature of the process. By taking the mean of various observations, the melting point of different metals has been determined with tolerable accuracy; and the determinations have been tabulated. Now, it is possible by effecting various combinations of metals with each other (alloys), to generate compounds corresponding to each degree of furnace heat comprehended within wide limits. If, therefore, specimens of various alloys,—the melting point of each determined,—be deposited in a furnace on an infusible tile, the amount of furnace heat may be determined by examining the tile, and ascertaining which alloy, highest in the scale of fusibility, has undergone fusion. Such is the theory of the process,—it only remains, therefore, to explain in what manner the composition of an alloy for any desired amount of heat may be made. The annexed formula conveys the required information:—

$$x = As + Bs'$$

whence x represents the temperature of fusion of the alloy to be compounded;

every part by weight of which must contain A parts of some metal fusible at *s* degrees, and B parts of another metal fusible at *s'* degrees of heat.

Violette adopted a modification of the foregoing process in conducting his inquiries relative to the charring of wood at various temperatures. In these experiments he determined the various temperatures up to 600° F. by a mercurial thermometer; above that point he used slips of different metals, antimony, copper, silver, steel, iron and platinum, the last of which he succeeded in melting in a furnace, the combustive force of which had been raised by great care to a higher grade than can ever be expected to occur in the general way. In connection with this subject, we insert a table of the fusibility of metals.

FUSIBILITY OF METALS.

	Guyton Morveau ("Ann. Chim.," 90,236).		Wedgwood & Dalton "N. Syst.," 1, 54).		Daniell.		Schwartz.	Rudberg.
	Cent.	Wedgw.	Cent.	Wedgw.	Cent.	Dan.	Cent.	Cent.
Bismuth	·247·	—	247	—	239	66	260	264
Tin	267	—	246	—	227	63	220	228
Lead	312	—	322	—	321	87	340	325
Zinc	374	3	371	—	342	94	500	
Antimony . . .	513	7	432	—			620	
Brass	—	—	—	—	1021	267	Pouillet	Prinsep
Silver	1034	22	—	28	1223	319	1000	999
Copper	1207	27	—	27	1398	364		
Gold	1381	32	—	32	1421	370	1200	
Cobalt	—	—	—	130				
White Cast Iron .	—	—	—	—	—	—	1100	
Gray do. .	4783	130	—	—	1915	497	1210	
Steel	—	—	—	—			1350	
Manganese . . .	5825	160	—	160				
Bar Iron	6346	175					1550	
Nickel, Platinum, Iridium, Rhodium	above	175						

Electrical Pyrometers.—The chemist and electrician are well aware of the fact, that electricity can be set in motion by heat; and that the amount of electricity developed, as estimated by the galvanometer, is proportionate to the amount of heat applied. Founded on an appreciation of this principle, has been devised by Nobili the most delicate of all existing measurers of temperatures within the range of thermometric degrees. Steinhil and Pouillet have taken advantage of the principle of this instrument to determine elevated furnace heat, but with indifferent success.

Perhaps, under the general denomination of "pyrometers," may here with propriety be included certain instruments, which have been brought into requisition for estimating the degree of heat and hot blasts. Occasionally, highly-graduated mercurial thermometers have been employed to this end; but more frequently instruments constructed on the principle of

the thermometer of Breguet, the description of which we therefore append. Breguet's metallic thermometer is based upon a common class-room experiment of the following kind:—If two thin strips or bars be taken of different metals, the expansion of which is unequal, as, for example, a slip of iron and a slip of brass, each about $\frac{1}{16}$th of an inch thick, 2 inches wide, and 15 inches long; and if these two slips be firmly rivetted together, a compound slip results, as represented in Fig. 12. When a slip of this kind is subjected to ordinary atmospheric temperatures, it remains straight; but if it be heated, the different expansiveness of iron and brass causes it to bend into a curve, as shown in Fig. 13, the convex side of the compound slip being, in all cases, that where is situated the metal of highest expansiveness (in this case brass).

Fig. 12.

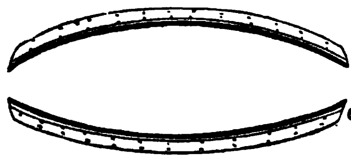


Fig. 13.

The principle on which Breguet's thermometer is founded will now be readily apparent. It consists of a slip of silver and one of platinum united face to face with solder, and coiled into a vertical spiral, the lower end of which is fixed, whilst to the upper end is attached an index or needle, moving over a graduated plate. It is evident that heat will cause this helix to expand, and the needle to change proportionately to the expansion. M. Breguet determined, by experiment, that the several amounts of this expansion for each part of the scale are comparable amongst themselves, and that his instruments, within the limits between the freezing and the boiling point of water, are reliable.

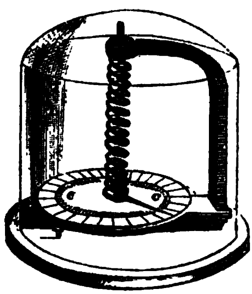


Fig. 14.

Although in the foregoing description we have assumed, for the sake of simplifying the matter, that the bar is merely compounded of two metals, platinum and silver, M. Breguet actually makes the spiral of his thermometer of three; accordingly the instrument is now made by interposing between the platinum and silver, a metal of mean dilatability—of pure gold, for example. So great is the sensibility of this instrument, that when inclosed in an air-pump receiver, and the air withdrawn, it indicates a reduction of temperature from 66° F. to 25° F (= 44° F.), whilst a sensitive mercurial thermometer fell only 3·6° F. The appended woodcut is a representation of one of Breguet's thermometers.

CHAPTER IV.

SPECIAL CHARACTERISTICS OF THE METALS—THEIR SOURCES AND DISTRIBUTION, THEIR CHEMISTRY, QUALITATIVE AND QUANTITATIVE—ASSAYING.

In addition to the systematic teachings of philosophy, each subject of philosophic inquiry has broad features and salient points of its own, which impress themselves on our observation at once, and often remain fixed in the memory when systems are forgotten. It shall be our endeavour to present the reader with a cursory glance at these, and thus conclude our introduction.

Iron.—Many of the "points" of this useful metal have already been determined in a collateral way, while others are reserved for special consideration, so that our present remarks will be few. In a metallurgic sense, the mineral sources of iron, as we have already indicated, are very extensive. Iron occurs in a native state, though not in quantities sufficient to be of value to metallurgy. Native iron is chiefly, if not altogether, of meteoric origin, and it has the peculiarity of containing nickel.

Sulphurets or Sulphides of Iron.—Iron is found combined with sulphur in several proportions, sometimes alone, at other times combined with other bodies. Of the former there are two sulphurets, the one known as magnetic pyrites, the latter as common iron pyrites, being, in chemical language, a bisulphuret or bisulphide of iron. There are also arsenical iron pyrites, ferric copper pyrites, and the mineral purple copper, which is a compound of sulphur, copper, and iron. The minerals *Weissgiltigers* and *Graugiltigerz* are components of sulphurets of copper, iron, and zinc. When arsenic is combined with the preceding, the mineral result is termed gray copper. Of similar qualitative composition, also, is the mineral called "*Tennantite;*" and the combination of sulphurets of antimony, of copper, of arsenic, and of silver, is known as copper-blende.

For smelting purposes the sulphurets of iron are useless, sulphur being a material very prejudicial to the quality of iron, and arsenic more prejudicial still. Smelting processes cannot well eliminate the two noxious agents; or, at least, other ores of iron are so numerous, and so much more readily worked, that the working of iron pyrites will not pay.

Oxygen Compounds of Iron.—Mineralogically considered, these are very numerous, and constitute the chief source of iron. There are two oxides of iron known to chemists, the protoxide and the peroxide, or sesquioxide: both of these occur as ores in nature. The mineral known as *specular iron* is pure sesquioxide; it constitutes the celebrated iron ore of Elba. This mineral, when hydrated, is also called *red iron-stone* and *bloodstone*, or hæmatites (red and brown). The minerals known by the names of brown-iron ore and bog-iron ore are composed respectively of sesquioxide of iron and water; in chemical language, "hydrated sesquioxide of iron." Bog-iron ore, however,

differs from the first in containing a portion of silicic and phosphoric acid. Clay iron-stone consists of iron mixed with a large amount of extraneous matters. The mineral termed chromate of iron is a compound of oxide of iron, and oxide of chrome, together with alumina and magnesia. The mineral termed Franklinite or dodecahedral iron-ore is a mixture of sesquioxide of iron, oxide of zinc, and protoxide of manganese. Automolite is a mixture of protoxide of iron and oxide of zinc, together with alumina, zinc, magnesia, and silica. Menaccanite, Titaniferous iron, Crichtonite, Nigrine, Iserine, Ilmenite, and a few other minerals, are combinations of protoxide with titanic acid. Wolfram is a compound of tungstate of protoxide of iron with tungstate of manganese. Skorodite is a compound of peroxide of iron with arsenic acid and water; besides which there are two arseniates of protoxide of iron (cubic iron and pitchy iron ore). The mineral known as spathose iron is a carbonate of protoxide of iron, often mixed with carbonate of protoxide of manganese; also lime, water, and magnesia. Besides the minerals already indicated, iron also occurs in several states of combination with phosphoric and silicic acids; also in union with soda, lime, alumina, manganese, magnesia, nickel, cobalt, cerium, yttria, and other bodies. Iron is, therefore, one of the most extensively diffused of all metals.

Chemical Characteristics of Iron.—Perhaps no metal can be so readily made evident by the operation of chemical tests as iron. Whether the testing process be conducted in the moist or dry way, the proofs are unfailing; though the former, we think, yields the surest indications. There are two oxides of iron, protoxide and peroxide (or sesquioxide), capable of uniting with acids, and forming salts—protosalts and persalts (otherwise called sesquisalts) respectively. The characteristic tint of the persalts is red or brown, and the protosalts green; or else the latter are colourless. It is difficult to get a pure protosalt of iron, so great is the tendency of this class of salts for oxygen. Usually, when iron is dissolved in sulphuric or hydrochloric acid for the purpose of subsequent testing or separation, the solution is a mixture of protosalt and persalt. The chemist always converts the whole into the state of percombination, by mixing it with a little nitric acid, and boiling. Practically, therefore, we have only to consider the tests and precipitants for peroxide of iron in combination, inasmuch as the state of peroxide, or peroxide combination, is that in which iron is always estimated in the moist way.

Tests of the presence of Sesquioxide of Iron in Solution.

Two of the tests of the presence of this substance are of especial importance: tincture or infusion of galls—a gallic acid which strikes a black colour (ink); and ferrocyanide of potassium, which yields a characteristic Prussian blue. These tests are so distinctive, that all others may be omitted.

Precipitants of Oxide of Iron.

Whenever the conditions of analysis permit, peroxide of iron is thrown down by ammonia heated to redness, taking care that no organic matter is

in contact with it, and weighed: every 80 parts by weight correspond with 56 parts by weight of metallic iron. Peroxide of iron and alumina, when they exist together in solution, are generally precipitated together by ammonia, the alumina being subsequently dissolved out by caustic potash. Occasionally, peroxide of iron does not admit of being thrown down by ammonia; in which case, succinic or benzoic acid is employed, and the metal thrown down in the condition of succinate or benzoate of the peroxide.

Determination of the presence of Iron qualitatively by the Blowpipe.

One remark applies to blowpipe metallic indications: either the metals are reduced to the metallic form, and thus rendered evident, or the metals, and their volatile combinations, are thrown off in a characteristic vapour; or, finally, their combinations yield characteristic tests with fluxes. The blowpipe indications yielded by iron are of the latter kind. We have already remarked that there must be two oxides of iron, the protoxide and the sesquioxide or peroxide, both capable of uniting with acids; there is also another, the black oxide: all three are concerned in affording indications of the presence of iron under blowpipe analysis. The blowpipe flame consists of two parts, each having a different function: the cone A (Fig. 15) is called the reducing flame, seeing that, by virtue of hydrogenous and carbonaceous matter not yet consumed, it elimates oxygen; B, on the other hand, is the oxidizing flame, seeing that it imparts oxygen to bodies under treatment. Minute portions of iron mineral, if mixed with flux, taken up in a platinum loop, and heated in the reducing flame, yield a glass, the colour of which is either bottle-green or copperas-green, according as protoxide or black oxide of iron is present; if held, on the contrary, in the oxidizing flame, the resulting glass will be red. By alternating the two flame cones, the change from green to red and red to green may be repeated indefinitely. A small particle of tin mixed with borax and peroxide much facilitates the reduction; but in this, and every other case involving the similar employment of metals, either a platinum loop should not be used, or the metal should not be allowed to come in contact with it. This latter condition is not difficult, if moderate care be exercised; it can easily be retained in the flux comprised in the platinum loop, without touching the platinum. Perhaps it is scarcely necessary to observe, that platinum, though alone a very infusible metal, readily fuses when heated in contact with tin, lead, zinc, &c. If the borax exhibits a blue instead of a green tint, the presence of cobalt is indicated; if violet, passing to red, manganese; if dark violet, changing to green when hot in the reducing flame, blue when cold—both cobalt and manganese are indicated.

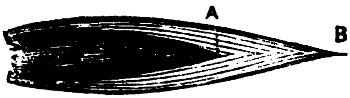


Fig. 15.

Furnace estimation of Iron on the small scale—The Iron Assay.

Although the estimation of iron by the moist process is the more accurate process, yet the direct extraction of iron from an ore containing it by process

of furnace or crucible agency is perhaps the more generally eligible, as affording clearer information respecting the actual quantity of iron obtainable on the large scale.

Assaying Furnaces.—The high temperature at which the fusion of iron ensues, requires that furnaces employed in conducting the assay of this metal should yield almost the strongest of which furnaces are capable, and that the crucibles employed should be of the most refractory materials. In Sweden, the furnace employed is known as Sefström's furnace, the characteristics of which will be presently described; but a blast-furnace of good construction answers perfectly well.

The very ingenious form of blast-furnace known as Sefström's, consists of an external cylinder of iron plate, about fifteen inches in diameter, and an internal cylinder of the same kind of material, separated from the preceding by an air-space of about the thickness of an inch. The connection of the two cylinders is established with each other by means of a rim of sheet-iron corresponding with the width of the air-chamber, and joining the two. Both external and internal cylinders have bottoms of sheet-iron plate, and the furnace is completed (all except the apertures in it, and which constitute its main peculiarity) by a lining of fine clay. The functional peculiarity of the Sefström furnace is this:—Ordinary wind-furnaces receive their blast through one aperture, and deliver the same in one blast on the entrance; but the Sefström furnace, though receiving its current of air by one blast passing into the air-chamber, circumscribed by the concentric cylinders, delivers the same air to the fuel by many blasts, each determined by a perforation through the internal cylinder and lining clay.

The accompanying diagram (Fig 16) represents the external cylinder of a Sefström furnace removed, its original situation being indicated by dots, and Fig. 17 shows the arrangement of this convenient little furnace when in use. Charcoal broken to the size of hazel-nuts is the fuel employed in Sweden; but a mixture of small coke and charcoal may be used instead.

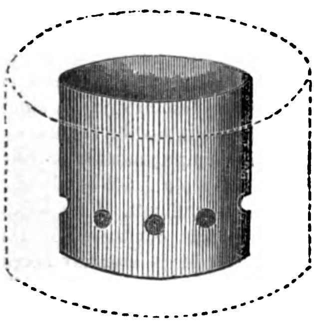


Fig. 16.

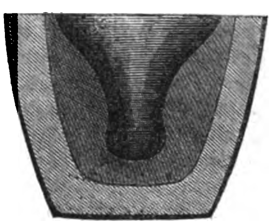


Fig. 17.

Whatever the kind of furnace employed, the crucible steps of the operation are as follow:—Having selected a crucible of proper dimensions, it must be lined with a coating of coarsely-powdered charcoal. This is done by moistening the charcoal, and ramming it into the crucible with a wooden pestle, in such manner that the pestle serves as a mould to form a cavity. The ramming process must not be accomplished at once, but by successive stages, and

the cavity must be accurately smoothed before the operation of lining is complete. The charcoal lining should be not less than half an inch thick at the thickest part, and the moulding should be so conducted that the resulting cavity may have the figure here represented, the small chamber-like contraction being the locality where the ore to be assayed is deposited.

Any kind of furnace, even a common smith's forge, may be used for assaying. Those fires which are supplied with Porter's patent tuyere are the best. This tuyere is represented in the accompanying engraving (Fig. 18); it has a conic valve, which is moveable from below by a lever, causing the tuyere to pass more or less blast, by diminishing or increasing its opening. Over this tuyere, or indeed any other, a small brick-furnace may be formed, and used as the one above.

Fig. 18.

A crucible is sometimes formed as shown in Fig. 19. It is of fire-clay; the foot is moulded to it, and serves as a stand; it is well baked, and, in fact, treated like any other crucible. The pot contains a lining, consisting of one part in weight of fine clay, and one of fine charcoal powder, moistened with a little water. With this mass the interior of the crucible is lined to about a quarter of an inch thick. A second lining is now formed of two parts carbon and one of clay, which is also moistened, the crucible filled with it, and the whole gently dried. Into this last lining a block of wood is pressed while the mass is still moist, and a cavity formed in the cone-like shape shown in the engraving, to receive the ore for smelting. The pot is now covered by a slab of fire-clay.

Fig. 19.

The ore to be assayed is finely powdered, and to every 100 grains of ore from 12 to 25 grains of borax, with about half as much chalk, and from 8 to 10 grains of hydrate of lime are added. This flux is well mixed with the ore, and all finely powdered and put into the pot, covered with a layer of charcoal-powder about a quarter of an inch thick, and the clay slab luted firmly to the crucible, which is placed in the furnace.

The perfect fusion of iron requires, under the best of conditions, so great an amount of heat, that it becomes a matter of great consequence to select for each particular sample of iron ore, the most appropriate flux.

To fulfil this condition with certainty and at once, a preliminary chemical analysis, by the moist way, of each particular ore, would be necessary; but the process of assaying is adopted, for the most part, to avoid the care and trouble,—the necessity of chemical apparatus, and chemical knowledge, in cases only requiring approximative results; hence, to make an elaborate chemical analysis precede by necessity the process of assay, would be to deprive the latter of its greatest claim to preference. I shall, therefore, state

the general principles to be remembered in the fluxing of particular samples of iron ore, and point out in what manner they may be rendered available, under the guidance of tact, and chemical judgment as distinguished from chemical demonstration. The main object of fluxes in all operations involving their use, is the formation of easily fusible slags. Now, practice has determined that the most fusible iron ores are those in which the carbonates of earths (of lime and magnesia) taken as one class, and the clayey and silicious matters taken as another class, are in the ratio of two to three. The point to determine, then, is, the amount of deviation from this ratio in any particular ore under consideration. When known, the clayey or argillaceous defect can be made up by China clay; and the defect of carbonates of earths by chalk. Without having recourse to quantitative analysis, a tolerably correct judgment may be acquired by treating a portion of the powdered ore, with dilute hydrochloric (muriatic) acid in a test tube. If no carbonates be present, there will be no effervescence; and the amount of effervescence will be proportionate to the amount of carbonate. This simple expedient will be usually enough for all practical purposes.

The quantity of iron ore, finely powdered, submitted to assay, must depend on the operator's means of applying furnace heat, and weighing. If a Sefström furnace be used, and a good assaying balance at hand, twenty grains will be ample; and in no case perhaps can the amount operated on be raised with advantage beyond 200 grains. Whatever the quantity it is to be deposited, mixed with the proper amount of flux, in the little cavity at the bottom of the charcoal crucible, and the crucible rammed full of as much powdered charcoal as it will contain, the crucible cover is luted with fire-clay, and the whole submitted to furnace heat. At first the heat should be gentle, but raised towards the end of the operation, until brought to the highest pitch which the furnace is capable of yielding. The process when conducted in an air-furnace usually occupies about an hour. At the expiration of that time, the heat is allowed to subside,—the crucible withdrawn,—allowed to cool; and when cold enough to be handled, the lid, firmly attached to the crucible, is broken off; and the iron, reduced to a button, if the operation has been successful, removed and weighed. The button will be found lying underneath a mass of vitreous slag. The quality of the button of iron is practically judged of by seeing whether it flattens under the blow of a hammer, or breaks. If the former, an approach to the condition of wrought-iron is indicated, and the ore promises to yield on the large scale a fine qualitative result: if the latter, an approach to cast-iron is manifested, which occurring in the presence, and under the influence of wood-charcoal, offers but little promise of a fine result when smelted on the large scale with coke.

Lead.—This is a very extensively diffused metal, though neither so widely disseminated nor so plentifully as iron.

(*a.*) *Sulphurets or Sulphides of Lead.*—(*b.*) *Oxides and Oxygen Salts of Lead.*

(*a.*) The principal lead ores, considered in a metallurgic point of view, are the sulphurets or sulphides of the metal; sometimes alone, in others together

with various other metals. The monosulphide of lead, *i.e.* the compound of one equivalent of sulphur and one of lead, constitutes the plentiful mineral galena, or lead glance, characterized by its beautiful cubic crystals of bluish-gray colour. This is the most common and the most important ore of lead, furnishing nearly all the lead of commerce; carbonate of lead yielding the remaining portion. Galena is fusible at a red heat; and if fused in a tube through which a current of atmospheric air is maintened, it may be sublimed in a sort of distillary process. When heated in the blowpipe flame, or even in the unaided flame of a candle or spirit-lamp, it evolves sulphur or sulphurous acid, according to the amount of air supplied. *Jamesonite* is a combination of sulphide of lead with antimony, iron, zinc, and copper; *Bournonite*, of sulphide of lead with antimony and copper; *Zinkenite*, of sulphide of lead and tersulphide of antimony; Siberian-needle ore, of sulphide of lead with tellurium and nickel.

Lead also is found united with chlorines, as chloride of lead, of which the mineral cotunnite, from Vesuvius, is an example, and in the form of boni-chloride of lead in the Mendip Hills of Somersetshire. It is also found united with selenium.

(*b.*) These, regarded as naturally occurring mineralogical bodies, are important bodies to the metallurgist. There exists native white-lead ore, carbonate of lead, and native black-lead ore *, and earthy carbonate of lead, which is carbonate of the metal mixed with alumina, silica, and peroxide of iron. Oxide of lead also occurs native combined with sulphuric acid (sulphate of lead), though sparingly. These may also be enumerated amongst the oxygen salts of lead—arseniates, phosphates, chromates, molybdates, tungstates, and vanadiates. Lead finally occurs naturally as sulphuret mixed or combined with other sulphurets, as of iron and copper; and in the metallic state united with the metals silver and copper.

Chemical Characteristics of Lead: (a.) The Moist Process.—(b.) Blowpipe Reaction.—(c.) Furnace Estimation of Lead on the Small Scale—The Lead Assay.

(*a.*) This metal, if dissolved, will be present in the condition of protoxide; for, though there are distinct oxides of lead, and several combinations of those oxides amongst themselves in the manner of acid with base, the protoxide of lead is the only one which unites with acids, and which will be therefore found in chemical solution. The chemical indications of the presence of lead in such a solution may be thus summarized:—

Hydrosulphuric acid and hydrosulphate of ammonia yield a black precipitate.

Ferrocyanide of potassium, a white precipitate; sulphuric acid, a white precipitate (sulphate of lead)—perhaps the most insoluble compound in nature after sulphate of barytes, from which it may at once be distinguished by the action of hydrosulphate of ammonia, which turns it black.

* Not plumbago, the substance usually termed blacklead, and which contains no lead.

If a piece of iron, zinc, or tin, be suspended in a lead solution, the lead is reduced to the metallic form, and deposited.

(*b.*) Lead salts and lead ores generally afford very characteristic results under blowpipe treatment. If a minute portion of plumbiferous metal be exposed on a piece of charcoal to the reducing portion of the blowpipe flame, the lead is speedily converted into yellow oxide, which, not being very volatile, is deposited in a ring almost close to the place where the fragment acted upon was rested. This is a very characteristic blowpipe test of the presence of lead.

(*c.*) Before subjecting an ore of lead to assay, it is necessary to determine whether it contain sulphur and arsenic, or whether it be free from one or both. Galena is the principal ore belonging to the former class, whilst carbonate of lead is the chief representative of the second.

Nothing is more easy than to effect, by preliminary experiment, the determination of the presence of arsenic or sulphur. Both are volatilized by the heat of a spirit-lamp, or the blow-pipe flame, and both yield characteristic odours—sulphur becoming sulphurous acid, which smells like the fumes of a burning brimstone-match; arsenic becoming changed to arsenious acid if heated alone, or escaping as volatilized metallic arsenic if heated in presence of deoxidizing matter, such, for example, as charcoal. Vaporous arsenic is known by its peculiar alliaceous or garlic smell.

(*a.*) *Assay of Lead Ores devoid of Sulphur and Arsenic.*—(*b*). *And of Lead Ores, containing Sulphur or Arsenic, or both.*

General Remarks.—Whatever be the ore of lead subjected to the process of assaying, care should be taken that the furnace heat be not more considerable than is absolutely necessary for effecting the desired fusion; otherwise, the result would be incorrect, because lead is a somewhat volatile metal, and portions of it would be dissipated.

(*a.*) This operation is exceedingly easy, nothing more being required than to mix about forty or fifty grains of the powdered ore with about one and a half times its weight of dried carbonate of soda (washing-soda, with all its water of crystallization driven off by heating), and one-tenth of its weight of powdered charcoal, and expose the whole to a graduated and moderate furnace-heat until the operation is judged to be complete.

In this and other cases involving the employment of carbonate of soda, the cruible must be considerably larger than the bulk occupied by the mixed ore and assay, because the carbonate tumifies and expands, especially during the early stages of the operation; and were not adequate space allowed, it would flow over the crucible and spoil the operation.

On removing the crucible from the furnace, it should be firmly seized by a pair of tongs, and gently tapped on a hard surface, in order that any little particles of lead not yet aggregated may collect into one definite bead. Practically, the quality of lead is judged of by the colour and degree of hardness of the bead. If a lead-smelter wishes to impress one with notions of extreme excellence of lead, he will affirm it to be "soft as butter."

If it be desired that still more accurate knowledge should be acquired of the constituents of the bead, chemical analysis, or at least a further process of assaying, must be had recourse to. As an example of the latter case—assuming the bead to contain silver or gold, or both—the two noble metals can be left, and their conjoined amount determined by the process of cupellation, to be hereafter described.

(*b*.) Two distinct processes of assay are now followed: the first consists in the employment of a flux of carbonate of potash or carbonate of soda alone, or the mixture of carbonate of potash and charcoal, known as black flux; the second, in subjecting the ore to the combined agency of furnace-heat, pieces of iron, and either carbonate of alkali, black flux, or borax. The first scheme of treatment we shall not further describe, as its indications are wholly unreliable; the second process is conducted as follows:—Two earthen crucibles being selected, their insides are smeared with black-lead, and a few clean nails are placed head-downwards in each. The ore to be assayed having been mixed with its own weight of carbonate of soda, is tightly pressed down about the nails; over this is placed a layer of common salt, and above the latter an amount of borax, equal to the weight of the lead ore to be acted upon; the whole is placed in a furnace, and heated to dull redness for ten minutes, then raised to bright redness for another ten minutes. The crucible (open from the first, so that each stage of the operation has been evident) is moved from the fire when the fusion is noticed to be complete, and the nails are removed by a pair of crucible tongs, taking care that during this removal each nail is well bathed in the fused mixture of borax and salt floating above. The crucible is finally to be smartly struck against a hard body, to cause the lead to aggregate into one button, the whole allowed to become cold, and the button weighed. This process is a modification, by Mr. Mitchell, of one long employed in France.

Copper.—This metal is not so widely diffused in nature as either iron or lead.

Copper is found in the uncombined state (native copper), especially in North America, where it occurs in enormous masses; in various sulphur combinations, either alone or more frequently united with sulphurets of other metals, as iron (purple copper), arsenic, and iron (Tennantite); with silver; with arsenic, iron, silver, and antimony in copper blendes; with tin and iron (tin pyrites); with antimony, silver, iron, and zinc; with antimony and silver (antimonial gray copper); with lead, antimony, and iron (Bournonite); with silver, iron, and arsenic(Gansekothigerz); with bismuth; with that metal in lead, nickel, and tellurium, constituting Siberian-needle ore. Combined with oxygen, it exists alone or combined with other metallic oxides, hydrated and non-hydrated as a mixture, or compound of oxide and chloride of copper (atacamite); and finally, in the condition of various oxysalts, such as carbonates (azurite and malachite); with arsenic acid and water, phosphoric acid and water, sulphuric acid and water, chromic acid, and chromate of lead; and lastly, silicic acid and water.

The sulphides and the dinoxides of copper, and the carbonates of copper,

are, however, of chief importance, regarded as mineralogical sources of this valuable metal. The principal copper-yielding districts are Cornwall, Devon, and the Isle of Anglesea, in Britain; Australia, Chili, North America, Cuba, Siberia, Norway, and Sweden. Wales is the great emporium of copper-smelting, more than half the total amount of manufactured copper in the whole world being produced in Wales. The copper ores there smelted admit of division in the following categories:—

I. Copper pyrites, combined with iron pyrites—the yield of copper being from 3 to 15 per cent.

II. Similar to the preceding, but richer, the yield of metal varying from 15 to 25 per cent.

III. Copper pyrites, comparatively free from iron or other injurious mixtures, and mingled with a variable amount of copper oxide. The yield of this class is from 12 to 20 per cent.

IV. Sulphurets of copper and oxides of copper, mingled with quartz, yielding from 25 to 45 per cent.

V. Ores almost free from copper pyrites, but rich in copper oxide, yielding from 60 to 80 per cent. of metal. Minerals of this rich class principally come from the Chilian mines.

Chemical Characteristics of Copper.

Copper in solution will exist as a salt of the protoxide, and is easily recognizable by chemical tests.

I. A piece of clean iron, if immersed in a solution of this kind, becomes speedily coated if the solution be not too dilute with metallic copper.

II. Ammonia develops a blue colour—either a precipitate or a solution, according to the amount of ammonia added.

III. Hydrosulphuric acid, and hydrosulphate of ammonia, throw down a thick precipitate.

IV. Ferrocyanide of potassium (prussiate of potash) yields a characteristic brown precipitate, thus distinguishing copper from every other metal except titanium, uranium, and molybdenum.

Quantitative Estimation of Copper in the Moist Way.

Copper is either estimated (*a*) in the metallic state thrown down by another metal, (*b*) in the condition of protoxide, or (*c*) oxysulphuret.

(*a*.) To precipitate copper in the metallic state, iron is immersed, when after a time the copper is thrown down: it should now be collected, washed, dried, and weighed.

(*b*.) To estimate copper as protoxide, it must have been previously ascertained that no other metal is in solution; caustic potash being then added, and the whole boiled, the oxide is then thrown down in the anhydrous condition. It is now collected, thoroughly washed, ignited in contact with atmospheric air, and weighed, every 39·7 parts corresponding with 31·7 parts of copper.

(*c*.) The precipitation of copper in the state of oxysulphuret has a very

wide application, being applicable not merely to solutions which contain no other metal, but to solutions in which any metal, save iron in proto-state of combination, cobalt, nickel, mercury, or silver, may be present. The process is conducted in the following manner:—Assuming an acid solution to have been made, an excess of ammonia is added, by which treatment all the oxide of copper is first precipitated; and, subsequently, on the addition of more ammonia dissolved; giving rise to the usual characteristic blue solution, the colour of which, as will be seen, is an essential point in conducting this estimation. Solutions of sulphuret of sodium being poured into this liquor from a vessel graduated in equal divisions, if the estimation is to be conducted volumetrically, or from one the weight of which, together with its contents, has been noted, if the estimation is to be conducted by weighing,—oxysulphuret of copper is at once precipitated. By taking due care, the point may be exactly determined at which the exact necessary quantity of sulphuret of sodium has been added; because it corresponds with the total disappearance of the blue colour originally presented by the solution. The amount of copper now present may be calculated by ascertaining the amount of sulphuret of sodium used. This point must have been previously ascertained for any solution of sulphuret of sodium, by a previous experiment; that is to say, a known quantity of copper having been dissolved, the amount of solution necessary to its conversion into oxysulphuret should be learned by actual trial. In this way, a test-solution of sulphuret of sodium, of tried and known strength, may be retained in bulk, and will be found very useful in conducting mineralogical investigations on copper.

The presence of no other metal, save those indicated, will interfere with the action of the above precipitating agent; because the alkaline sulphuret does not begin to act until all the copper has been precipitated; an occurrence shown, as we have seen, by the discoloration of the original solution. Silver, as we have already indicated, is one of the metals which prevents the correct action of sulphuret of sodium; but if a little hydrochloric acid be added to the original solution, any silver which may have been contained in it will be precipitated in the state of chloride, before the application of the copper precipitant.

Besides the foregoing methods of copper extraction, which are most generally applicable, and therefore the most useful to be remembered, there are many others eligible in certain cases. Thus it is well known that the metals iron, cobalt, nickel, zinc, manganese, titanium, chromium, and uranium, are not precipitated by sulphuretted hydrogen, from solutions in which an excess of hydrochloric acid exists. Copper, however, is thrown down as sulphide under these conditions; whence arises an easy means of effecting its isolation.

When copper exists in nitric acid solution, together with cadmium, bismuth, and lead, it may be separated by carbonate of ammonia, which only dissolves the copper. In a similar manner may copper be separated from alumina and the sesquioxides, of iron and of chrome; but this procedure is not so reliable as precipitation of the copper by hydrosulphuric acid. The best method of effecting the separation of copper from lead, however, depends on the fact that

sulphate of lead is a very insoluble, and sulphate of copper a soluble body; hence if the mixed metals be dissolved in nitric acid, and sulphuric acid be subsequently added to the solution, all the lead descends in combination with sulphuric acid, as sulphate of lead. Instead of separating this precipitate, the whole mixture should be evaporated to dryness until no more free sulphuric acid remains. The residue being now moistened by nitric acid, all the copper will be taken up in the condition of nitrate, and may be now thrown down or otherwise estimated by one of the processes already described. All the lead will, of course, remain in the condition of sulphate of lead.

The separation of copper from tin and antimony may readily be effected by taking advantage of the circumstance that the two latter metals, instead of being dissolved by treatment with nitric acid, are converted into compounds insoluble in that menstruum (stannic and antimonic acids). In the case of antimony, however, the indications are not so precise, antimonic acid being slightly soluble in nitric acid. A better plan of separating copper from antimony consists in acting upon a solution of the two metals in nitromuriatic acid by ammonia, and then pouring in an excess of hydrosulphate of ammonia, which dissolves the sulphide of antimony, but throws down the sulphide of copper. The same treatment may be adopted for effecting the separation of copper from tin, and arsenic.

Estimation of the Presence of Copper qualitatively by the Blowpipe.

Few mineral substances admit of recognition with greater ease, or certainty, than copper, under blowpipe investigation. This facility depends on the ready change of copper into the condition of red oxide—the oxide which has the composition of 63·4 of copper united with 8 of oxygen. When developed, this oxide tinges borax with its characteristic colour,—whence the presence of copper is demonstrated.

The practical determination of copper by the blowpipe, is conducted as follows:—A loop being made at the extremity of a piece of small plantinum wire, is moistened by water or on the tongue, and dipped into some powdered borax, when a little borax will be taken up. The borax is now to be fused, and whilst yet soft is to be dipped into some of the powdered mineral, so that a little may adhere. The whole is now to be fused again, and retained in fusion some time; for the purpose of evolving sulphur, arsenic, or any other volatile matter; the presence of which might prejudice the subsequent operations. The next point to be held in view, is the reduction of any copper which may be present, to the state of red oxide. The platinum loop and its contents should therefore be acted upon by the reducing flame. If the characteristic redness of the oxide of copper be developed, nothing more remains to be done; but if it be not, the aid of some deoxidizing material must be sought. A very small particle of tin is usually employed for this purpose: if any copper be present, the combined agency of the tin and the reducing flame immediately brings the metal to the condition of red oxide.

Furnace Estimation of Copper on the Small Scale—The Copper Assay.

Before an assay of copper ore can be satisfactorily performed, the operator must determine the nature of the materials associated with the copper. For practical purposes, copper ores arrange themselves in three classes:—

I. Ores devoid of any other metal (calcigenous metal) save iron.

II. Ores containing, besides iron, sulphur and selenium, or both; but no arsenic.

III. Ores containing sulphur and selenium, or both; together with arsenic, iron, and other metals.

Discrimination of the presence of Sulphur and Selenium.

To effect this discrimination, a small fragment of the ore may be heated either in the spirit-lamp flame, or the oxidating blowpipe flame, supported in either case on an iron wire. If sulphur be present, sulphurous acid will be generated; recognizable, most likely, by its peculiar odour of a burning brimstone match; selenium will be indicated by the odour of horseradish. The latter constituent is, however, very rare.

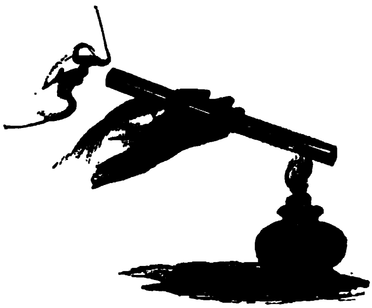


Fig. 20.

Instead of heating the fragment of ore as described, more powerful indications of odorous matter will sometimes result from heating it in a glass tube, open at both ends, and held over a spirit-lamp flame, as represented in Fig. 20.

Discrimination of the presence of Arsenic.

The peculiar alliaceous smell developed when a mineral containing arsenic is heated in contact with deoxidizing matter—such, for example, as charcoal—we have already (page 62) pointed out. Nevertheless, this test of the presence of arsenic is not always satisfactory, on account of the coincident generation of sulphurous acid; the strong odour of which masks and conceals the odour of the former.

An ingenious, and at the same time a very easy method of discovering the presence of arsenic, consists in the application of what is called Marsh's test, the indications of which depend on the formation and the subsequent combustion of arseniuretted hydrogen gas. Many different forms of apparatus have been devised for the performance of this experiment. The following has the advantage of great simplicity, and, if properly managed, amply serves every useful purpose to the extent of mineralogical requisition:—

Having procured a five or six-ounce bottle, attach to its mouth a perfo-

rated cork, with a piece of tobacco-pipe stem attached to the perforation, as represented in the accompanying diagram (Fig. 21).

First pour into the bottle a mixture of sulphuric acid and water, in the proportinate ratio of one to six. Then throw in a teaspoonful of the material to be acted on, previously reduced to powder; and agitate. Next add some fragments of zinc; and now thrusting the perforated cork into the mouth of the bottle, let the apparatus stand until the operator feels assured that the developed gas has expelled all the atmospheric air originally contained in the bottle. Were this admonition not attended to, there would result an explosion—one, however, not dangerous. The operator next applies flame to the issuing gases, and holds a piece of white earthenware (a plate or saucer) in the burning jet. If arsenic be present in the ore, a black circular stain will be produced on the saucer or plate. This is an exceedingly delicate test—far more delicate than the metallurgist requires; it may even, if not controlled, lead to false conclusions, owing to minute traces of arsenic sometimes present in the metal zinc. All error, however, from that source may be avoided by previously examining the zinc by a separate experiment; every part of the instructions given being followed except the addition of powdered ore to the other materials.

Fig. 21.

Assay of Copper Minerals of the First Class.

A portion of the ore having been reduced to powder is intimately mixed with about three or three and a half times its weight of black flux, and removed into a crucible about half full. The crucible thus charged is next exposed (open) to furnace-heat until the whole contents have been melted, and the fluid becomes tranquil. The crucible is now exposed for about fifteen minutes to the highest power of furnace heat. Finally the crucible is withdrawn, gently tapped on a hard surface to promote aggregation of the reduced copper into one mass; the latter allowed to cool, withdrawn from the crucible, and weighed.

This process is not very satisfactory for ores which contain less than 10 per cent. of copper. The best method of treating pure copper ores is to subject them to a preliminary fusion with sulphur, and bring them into the category of the second class, now to be described.

Assay of Copper Minerals of the Second Class.

The first operation in the assay is roasting, by which means a portion of the sulphur is driven off in the condition of sulphurous acid; whilst another

portion of the sulphur being converted into sulphuric acid, sulphate of oxide of copper is generated; finally the latter is decomposed, and oxide of copper remains, which readily yields up its oxygen when heated in the presence of black flux, and evolves metallic copper.

The roasting operation is conducted in an open crucible in the following way:—The ore, reduced to powder, is deposited in the crucible, and the latter placed in a slanting position amidst the coke of an air-furnace, the draught of which has been brought by damping to a very low degree—for it is essential that the copper sulphuret be not fused at this early stage of the operation. Of course the roasting operation, involving, as it does, free contact with atmospheric air, must be conducted in an uncovered crucible; and the operator, by smelling through an iron or earthenware tube, the lower extremity of which is held over the crucible mouth, should assure himself from time to time as to the progress of sulphurous acid evolution. Meanwhile the crucible contents are to be stirred from time to time with an iron rod, in order to bring about atmospheric contact with every portion of the ore. When the smell of sulphurous acid is insignificant, the crucible, from dull redness, should be heated to bright redness, and the heat continued until sulphurous acid is no longer expelled. Finally, the crucible is to be heated to full whiteness for not less than ten minutes, afterwards removed from the furnace, and its contents permitted to cool.

The smelting operation, properly so called, now begins; it consists in mixing the roasted ore with four times its weight of black flux, underneath a layer of borax, and heating in a furnace for about half an hour to the fusion-point of copper. Finally, the crucible is to be removed and gently tapped to promote metallic cohesion; then either the copper may be dexterously transferred at once to an ingot mould, or obtained by breaking the crucible when cold.

Assay of Copper Minerals of the Third Class.

The assay operation for these ores is essentially the same as the last, only the process of roasting is more difficult, because the ore is more fusible. The temperature, therefore, at which the roasting is first commenced should be gentle, and only increased to full redness after the chief portion of arsenic and sulphur has been evolved. Evolution of the arsenic may be greatly promoted by adding to the powdered mineral a little powdered charcoal from time to time, and stirring the whole well together. When the operation of roasting is deemed complete, the smelting part of the operation proper is accomplished precisely as directed for minerals of the second class: however, the resulting button of copper will always be contaminated to such an extent, that a subsequent process of refining will be necessary. This refining operation is identical with cupellation, properly so called, and is conducted in the following manner;—

The bead of copper being placed on a little cup or vessel of porous bone-earth, some pure lead is added, and the whole exposed to a current of highly

heated air. The lead now oxidizes—forms litharge, which has the property of dissolving other metallic oxides, and forming a glass or slag, which sinks into the pores of the cupel. In the present case, the metal whose removal is aimed at is arsenic. As regards the contrivances for effecting cupellation (in this case termed refining), the operator requires a cupel—usually home-made,

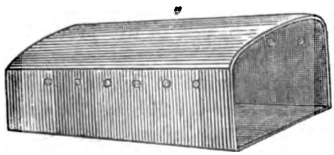


Fig. 22.

by means of powdered bone-earth, and a cupel mould; also a little perforated oven, technically called a *muffle*, and represented in the accompanying diagrams (Figs. 22 and 23).

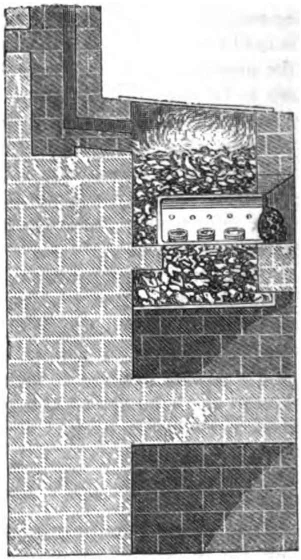


Fig. 23.

Great practice is required in performing cupellation with advantage, even where gold and silver are concerned: still more care is requisite in conducting the operation of copper refining.

When the principles on which the cupelling operations are based are well considered, it will be evident that a metal somewhat easy of oxydation like copper must incur appreciable loss when subjected to cupelling: and that although arsenic and the other impurities mingled with copper ores of the third class be the substances which chiefly disappear during the process of refining by cupellation, still the loss of copper will be far too considerable to be neglected. It is, therefore, well to check this loss by a second cupelling operation, performed on a bead of pure copper equal in weight to that of the impure copper; to effect the purification of which, the refining operation is applied.

Tin.—This metal exists in but few localities, but in these it is somewhat abundant. The chief tin localities are Cornwall and Devon; the East Indies, Saxony, and Bohemia. Stanniferous sand is found in Brittany; but the amount is too small to pay for extraction. The principal ore of tin is the binoxide, but the metal also occurs in combination with sulphur and arsenic.

Chemical Characteristics of Tin.

Perhaps the most striking characteristic of tin when operated on by the moist process, is its insolubility in nitric acid; which body at once oxidizes it, and brings it to the condition of stannic acid. Nitric acid gives rise to a parallel result when caused to act upon antimony. Hence neither tin nor

antimony admit of solution in nitric acid; and founded on this circumstance arises an easy means of separating them from many other metals.

Tin solutions may occur in two different states,—namely, as proto or per-combinations. The former correspond with the protoxide; they are represented by the protochloride of tin, and solutions holding the protoxide. The mineralogist has seldom the necessity to concern himself with the minute characteristics of these solutions. Having once determined the presence of tin,—which the blowpipe operation, combined with the relation of tin to nitric acid, will generally accomplish,—his next concern is to estimate its amount; to this end, he changes the tin into insoluble stannic acid, washes, ignites, weighs, and calculates the amount of tin. Every 75 parts of stannic acid (peroxide) correspond with 59 of tin.

Usually the stannic acid from which the quantity of tin is deduced, is obtained by decomposing sulphide of tin by treatment with nitric acid, as will be now explained. When it is intended to throw down tin as a sulphide from a solution, a proto-solution of tin must be employed, such as will result from the solution of tin in hydrochloric acid, the operation being performed in a flask so as to prevent unnecessary contact with atmospheric air; otherwise the solution might be partially brought to the state of per-combination. The solution, moreover, should hold a considerable excess of hydrochloric acid. A current of hydrosulphuric acid gas is now to be transmitted until the liquid will absorb no more. The operation should be performed in a flask; and when the transmission of gas is complete, the flask, being closed, should be removed to and allowed to remain in a warm place (about 140° F.) for some hours. Meantime, the sulphide will fall, and may afterwards be collected in a filter, and carefully washed. The sulphide of tin is next to be converted into stannic acid or binoxide of tin, by pouring warm nitric acid over it. If traces of any other metal should have been thrown down by the hydrosulphuric acid simultaneously with the tin, these traces, all except antimony, will be dissolved by the nitric acid. The stannic acid produced is to be washed, heated, weighed, and the amount of tin present deduced from its composition.

Estimation of the presence of Tin qualitatively by the Blowpipe.

The tin mineral under examination may either be in the condition of peroxide, or sulphuret (tin pyrites) respectively, alone or mixed with other bodies. If tin pyrites be heated in the oxidating flame on a piece of charcoal, the presence of sulphur is indicated by the evolution of sulphurous acid: the further reactions are due to the peroxide of tin generated. Peroxide of tin becomes highly incandescent when subjected to the oxidating flame, but in other respects it remains unchanged: when removed to the reducing flame, it loses its oxygen and leaves metallic tin.

Peroxide of tin and borax exposed to the oxidating flame, yield a white opaque glass if the borax be saturated with oxide; if otherwise, the glass will be transparent. The fact may here be remembered as serving to fix on the recollection a blowpipe indication of tin, that the opaque white glass of

commerce obtains the quality of opacity, either from oxide of antimony, or of tin.

Furnace Estimation of Tin on the Small Scale—The Tin Assay.

Notwithstanding that the oxide of tin is completely reduced by contact with charcoal at a red heat, the highest heat capable of being yielded by a wind furnace is necessary in order to conduct the chemical assay; and even then the process of reduction is unsatisfactory, except the oxide of tin, contained in tin ore, have been previously freed from much of the silicious and other associated matter, wherewith it is naturally mixed or in combination. This may be effected by agencies partly chemical, partly mechanical, as the following statement will explain.

Preliminary Operations.

The tin ore having been carefully pulverized, is mixed with a little powdered charcoal; afterwards the mixture is roasted; by which treatment much or all of the iron pyrites in combination with it will be decomposed, and the fixed residue will be rendered specifically lighter than the oxide of tin to such an extent, that on shaking the whole together with water, the former may be separated in great measure by decantation; leaving the real oxide in a competent state of concentration for the real smelting process to be applied with advantage. If, however, the silicious gangue associated with the ore be inconsiderable, and iron pyrites be the chief associated body, a moist preliminary treatment may be advantageously applied. The powdered ore being boiled with nitro-muriatic acid, holding nitric acid in excess, the pyrites will be decomposed and dissolved, whilst the oxide of tin present remains untouched. The latter may then be collected on a filter, and subjected to the smelting operation, after preliminary calcination, to effect the evolution of any traces of sulphur which the process of solution may have caused to be present.

The Assay Proper.

The high temperature required for the reduction of native tin oxide has already been mentioned. The operation should always be conducted in a charcoal-lined crucible, and the ore should be mixed with about half its weight of a flux, composed of carbonate of soda and borax in equal portions, or else a flux composed of three parts of carbonate of soda to one of lime.

Zinc.—Since the discovery was made that zinc at a certain temperature can be rolled into sheets, it has been applied to a variety of uses, more especially those for which tin plates had been hitherto employed. The only minerals from which zinc can be extracted remuneratively are calamine (carbonate of zinc) and sulphide of zinc (zinc blende): the former is of greater importance. The principal localities wherein calamine is found are Tarnowitz in Silesia, the mines of Vieille, and Nouvelle Montaigne near Aix-la-Chapelle. England yields a limited quantity, but our mineral stores of zinc blende are considerable.

Chemical Characteristics of Zinc.

The most striking chemical characteristic of zinc treated by the moist process is the white sulphide it yields when thrown down by hydrosulphuric acid, being the only calcigenous metal which has this property. Manganese yields no precipitate with hydrosulphuric acid; though with hydrosulphate of ammonia the precipitate it gives is *almost* white. Zinc is precipitated white both by hydrosulphuric acid and hydrosulphate of ammonia.

Zinc is usually subjected to quantitative estimation by the moist process by throwing it down as carbonate; changing the carbonate to zinc oxide (there is but one oxide of zinc), and calculating from the latter the actual amount of zinc present.

Occasionally, instead of precipitating zinc as carbonate at once, it is thrown down by hydrosulphuric acid, or hydrosulphate of ammonia, as sulphide of zinc, the latter dissolved in hydrochloric acid; to which solution carbonate of soda being added, the zinc is now thrown down in the form of carbonate.

Estimation of the presence of Zinc qualitatively by the Blowpipe.

If a thin piece of metallic zinc be held in the flame of a candle or a spirit-lamp, it burns and is converted into a white flocculent oxide, to which the older chemists applied the term "*lana philosophica*," or philosopher's wool. Indications of this sort of change are afforded under blowpipe treatment, and are amongst the most valuable signs that instrument is capable of giving as regards the presence of zinc.

A fragment of zinc mineral, if heated on a piece of charcoal in the oxidating part of the blowpipe-flame, fuses into a bead, which appears yellow when hot, becoming more or less white in cooling. Changing the position of the assay by removal to the reducing-flame, the zinc is first brought to the metallic state, which immediately oxidizing, the oxide burns and is deposited over the charcoal in small flakes, constituting a deposition of the "*lana philosophica*" already adverted to.

Furnace Estimation of Zinc on the Small Scale—The Zinc Assay.

The igneous metallurgy of the metal zinc on the large scale is no less easy, than the same on the small scale (assaying) is difficult and unsatisfactory. The facility in the former and the difficulty in the latter case, are determined by the solubility of zinc, which prevents its being drained like other metals in the condition of a button. It must either be distilled or collected, and its amount estimated; or the quantity of zinc present in an ore must be thrown off by violent heat, without subsequent condensation, and the quantity present estimated by the loss experienced. To Berthier we are especially indebted for the best information we possess concerning the igneous estimation of zinc on the small scale. His division of the subject is that consequently which we shall adopt in our outline of the subject.

Berthier divides all zinc ores capable of being dealt with, by the process of igneous assay, into four classes:—

1. Zinc ores containing oxide of zinc uncombined with silicic acid.
2. Those containing oxide of zinc partially or wholly combined with silicic acid.
3. Those in which the metal is wholly or partially combined with sulphur.
4. Combinations of zinc with other metals (zinc alloys).

(1.) The reduction of ores of the first class is very easy; the only practical difficulty consists in collecting and estimating the metal evolved. Inasmuch as oxide of zinc readily loses its oxygen when heated in contact with deoxidizing bodies (coal, coke, charcoal, hydrogen, carbonic oxide, or carburetted hydrogen), all that has to be done consists in so arranging the apparatus that the oxide of zinc may come into contact with either of the preceding at a suitable temperature: red heat is sufficient for the mere accomplishment of reduction, but full white heat is necessary to effect the subsequent distillation or evolution of the vaporous zinc. The best apparatus for conducting the operation is an earthenware retort, made of highly refractory materials, and having a long neck; or, what is still better, a clay retort the neck of which is short,—the tubular length necessary to promote perfect condensation being given by luting in a porcelain tube. Nothing can be more simple in theory than the process here described; it is, nevertheless, attended with particular difficulties, the nature of which will be obvious, when they are once stated. Firstly, it is not an easy matter to evolve every trace of zinc in the vaporous form: hence an error proportionate with the amount remaining will be the consequence;—secondly, the vaporous zinc which it is the object of the assayer to condense in the metallic form, is partially converted into oxide;—and lastly, the crust of zinc deposited on the latter cannot always be readily detached: much of the latter difficulty may be, neverless, obviated, by smearing the interior of the tube with plumbago, so as to impart a highly polished surface. Still, despite all precautions, a variable proportion of zinc will remain so distinctly attached to the tube, that all endeavours to effect its removal by mechanical force will be fruitless. It must, therefore, be dissolved by nitric acid, which will generate nitrate of oxide of zinc, which being evaporated to dryness and calcined, anhydrous oxide of zinc will be the result: four-fifths of which by weight will be equivalent to the amount of metallic zinc represented by the oxide; and if added to the figure representing the amount of metallic zinc attached, the whole quantity of that metal distilled over will be indicated.

Inasmuch as the preceding operation necessitates the employment of a retort (a very inconvenient form of instrument), some operators prefix a crucible, taking no heed of preserving by condensation the zinc which escapes, but merely raising the furnace temperature to such a grade that all the zinc shall be evolved and dissipated in the furnace.

For this operation a charcoal-lined crucible is required, precisely similar to that already described as being employed in performing the iron assay; and the heat is pushed almost to the highest degree capable of being yielded

by a powerful air-furnace. The best flux to be employed in conducting this operation is a mixture of black flux and borax. Supposing this operation to have been performed, the fixed materials remaining in the crucible will be a mixture of slag and reduced fixed metal, iron—always present in zinc ore. Now the iron was originally present in the form of oxide of iron; therefore oxygen will have been evolved in the state of carbonic oxide or carbonic acid.

The operator now proceeds to get the iron out of the slag, which he accomplishes by pounding the mass, and abstracting the iron by a bar-magnet. Of course the non-attracted portion of the fixed matter is the amount of slag; and representing the quantity of oxide of zinc originally present by Z, the weight of iron, of slag, of oxide of zinc (Z), and oxygen of the oxide of iron, added together, will give the original weight of the ore. In point of fact, these data give all the information the assayer requires, by the operation of obvious algebraical equation formulæ, the elements of which have been summarized by Berthier as follows:—

Assume that

$$\begin{array}{rl} \text{W} = \text{crude ore} = \text{calcined ditto} = & w \\ t = \text{fixed fluxes added} \ldots = & t \\ \hline & w + t \end{array}$$

$$\left.\begin{array}{l} \text{Gross metal} \ . \ f \\ \quad \text{,, slag} \ . \ . \ s \\ \quad \text{,, oxygen} \ . \ o \end{array}\right\} \begin{array}{l} \text{Total } f + s \,\} \, f + s + o \\ \text{Oxide of zinc, } w + t - f - s - o \end{array}$$

Flux added, t

Earthy matters, $s - t$.

(2). Silicic acid, obviously, is not affected by carbon alone: hence ores of zinc, combined with silicic acid, require to be treated by a mixture of carbon and a flux. Lime or magnesia, with or without borax, may be conveniently employed for this purpose; otherwise the steps of the smelting operation are precisely similar to those already indicated as adopted for minerals of the first class.

(3). Zinc ores of this class—*i.e.* ores which contain sulphur—require to be subjected to a preliminary operation of roasting, for the purpose of converting the sulphur into sulphurous acid, before the final operation of distillation or of vaporous dissipation from a charcoal-lined crucible can be efficiently applied; otherwise, the remaining steps of the smelting operation are precisely as before indicated.

The difficulties and imperfections attendant upon the correct estimation of zinc as an ore by either of the processes of dry assay, should determine the operator to have recourse, whenever practicable, to some variety of the moist process. In addition to the chemical means of zinc already described, we may here mention that the non-metallic constituents of carbonate of zinc (calamine) and sulphide of zinc (zinc blende) may be readily determined by any chemical operation. The non-metallic constituents of the former, the proportions of which it is desired to estimate, are water and carbonic acid. The quantity of water may be determined by strongly heating some powdered calamine in a glass tube, connected with

another tube holding fused chloride of calcium. All the water evolved must pass through the latter, which will absorb it, and derive a proportionate increase of weight; by weighing the chloride of calcium tube and its contents before and after the operation, it is evident the quantity of water evolved will be determined. The total amount of carbonic acid and water contained in any specimen of calcium can be determined by strongly heating a portion of the ore in a platinum crucible, when both water and carbonic acid will be driven off. Finally, the amount of silicic acid may be determined with sufficient practical accuracy by treating a portion of the powdered ore with hydrochloric acid, and regarding the portion remaining undissolved as silicic acid; and ammonia being added to the solution, the whole of the oxide of zinc may be precipitated.

If it be wished to ascertain by the moist process how much sulphur is contained in a given portion of sulphide of zinc (zinc blende), this determination admits of being readily made by solution in nitro-muriatic acid (aqua regia) with heat: when all the sulphur will be converted into sulphuric acid, and may be precipitated in the ordinary manner with a salt of baryta; whilst from another portion of solution similarly affected, the total amount of zinc present may be discovered by precipitation with ammonia or oxide of zinc.

Antimony.—This metal is occasionally found native in Sweden, France, and Germany, though the occurrence is rare: antimonial ores are alone of commercial importance in furnishing our sources of the metal.

Oxide of Antimony.

This is a somewhat rare mineral, occurring in Hungary, Saxony, and some other localities. It is of little importance, however, considered as a source from which antimony is obtained commercially. The only antimonial mineral having commercial importance to any considerable extent, is the ore next to come under consideration.

Sulphuret or Sulphide of Antimony.

The chief localities where this mineral is found are Hungary, Stolberg in the Hartz, Auvergne, Dauphiny, Spain, Cornwall, and the Island of Borneo. In composition it is a tersulphide of the metal, being a composition, therefore, of three equivalents of sulphur plus one of antimony.

Chemical Characteristics of Antimony.

Antimony is a brittle brilliant metal of silvery whiteness: its density is about 6·8, and its fusing point about 848° F. It crystallizes when slowly cooled in forms belonging to the rhombohedral system. This metal does not readily become oxidized when exposed cold to air, even though the air be moist, but it readily oxidizes if left uncovered at the temperature of fusion. Like arsenic, but to a less considerable extent, antimony forms a gaseous combination with hydrogen; and if strongly heated in a current of air or any gas, it undergoes a sort of distillation. Antimony is not dissolved when acted on by sulphuric acid and water—nor even by strong sulphuric acid, except

heat be applied, when the acid is decomposed with the evolution of sulphurous acid gas. Finely-powdered antimony is dissolved by hydrochloric acid, with the evolution of hydrogen gas; and nitro-muriatic acid dissolves it with still greater facility, provided nitric acid be not in excess. The action of nitric acid on antimony is peculiar, and has already been adverted to. It at once oxidizes the metal, converting it into a white powder, *antimonic acid.* Tin and antimony, treated with nitric acid, both generate a white insoluble powder.

If, however, the problem be that of determining the presence of antimony already in solution, hydrosulphuric acid or hydrosulphate of ammonia affords not only a ready means of qualitative discrimination, but a means of throwing down all the antimony, preparatory to obtaining it in the metallic form. The sulphide or sulphuret of antimony thrown down has a well-marked orange colour, and can scarcely be mistaken for any other sulphide. It is true that arsenic, cadmium, and tin, in the state of percombination, all yield yellow precipitates when either hydrosulphuric acid or hydrosulphate of ammonia is added to these solutions; but the colour is so far distinct from the deep orange tint of sulphide of antimony, that a practised eye will not be misled. When the sulphide of antimony has been thrown down in the course of experiment, and the operator wishes to reduce it to the condition of metallic antimony, this is best accomplished by placing it dry in a tube of Bohemian glass, about eight inches long and half-an-inch diameter; transmitting hydrogen gas over it, and simultaneously applying the heat of a spirit-lamp flame. Thus treated, the sulphur of the sulphide unites with hydrogen to form hydrosulphuric acid gas, which passes over; and metallic antimony is left in a pulverulent state. It may be readily withdrawn from the tube, and its quantity estimated by weighing. The process here described is not chemically unexceptionable; inasmuch as minute traces of the antimony may unite with hydrogen, and pass over as antimoniuretted hydrogen gas. The objection, however, is too slight to affect mineralogical results. A ready method is available for determining the instant at which the transmission of hydrogen has been sufficiently prolonged, by holding from time to time a slip of paper, moistened with acetate of lead solution, near the open extremity of the Bohemian glass tube. So long as the decomposition of sulphide of antimony is going on, hydrosulphuric acid will be evolved; and this, as is well known, has the property of blacking a salt of lead. When, however, the decomposition of the sulphide of antimony is complete, hydrosulphuric acid is no longer generated; whence it follows that the lead test-paper will no longer be affected with blackness.

Blowpipe indications of Antimony.

Whether the antimonial ore subjected to examination be oxide or sulphide, the final indications of the presence of the metal will be similar, and will depend upon the former. Oxide of antimony is a rare mineral, as we have already indicated: it will rarely, therefore, come under mineralogical notice as an ore. Oxide of antimony—otherwise called antimonic acid—will frequently occur as the result of the action of nitric acid on antimonial compounds. Let

us assume that a certain mineral, when digested with nitric acid, does not dissolve, but yields a white powder: the latter will be either an oxide of antimony or of tin. It may be readily determined to be the oxide of antimony by the following blowpipe reactions. Heated on charcoal in the oxidating flame, it simply evaporates, to be deposited a little way off on the same piece of charcoal unchanged. If heated, however, in the reducing flame, it loses oxygen, and the metallic antimony set free sublimes: a portion of it uniting with oxygen is again deposited as white oxide; but the greater portion is altogether dissipated. If, instead of heating it unmixed, it be incorporated with carbonate of soda, and exposed to the reducing flame, a bead of antimony is speedily formed.

To these means of discrimination, the effects of blowpipe treatment, in conjunction with borax as a flux, may be added. Heated in the usual manner with borax in a platinum loop in the oxidating flame, a clear yellow glass results, which, if removed to the oxidizing flame, soon becomes gray or blackish, owing to the reduction of oxide of antimony, and the liberation of the metal. If, however, the reducing flame be continuously applied, the glass becomes colourless, simply on account of the total volatilization of the antimony.

Qualitative estimation of Antimony by the Dry Process—The Antimony Assay.

The reduction of antimony, whether from the condition of oxide or sulphide, is very easy; but on account of the volatility of the resulting metal, care is requisite lest errors creep in from this cause. If the problem be to determine the amount of antimony present in an oxide of antimony, the reduction is easily effected by the process of heating with charcoal; but perhaps the best means of performing the operation consists in using a crucible lined with charcoal, as employed in the process of iron and zinc assaying: but if the reduction of sulphide of antimony be in question, the mere aid of charcoal is not enough. In this case there are two processes which may be recommended, either (*a*) fusion with a mixture of carbonate of soda, iron, and charcoal, or (*b*) with cyanide of potassium.

(*a*.) Sulphide of antimony may be effectually decomposed by fusion with iron alone; but the process cannot be recommended, because the specific gravities of sulphide of iron generated, and the metallic antimony reduced, are so nearly identical that the two do not well separate, except the process of fusion be so long continued that portions of the antimony will be lost by volatilization. Every 100 parts of sulphide of antimony require about 42 parts iron filings, 45 of carbonate of soda, and 5 of charcoal. Instead of iron filings, iron nails are sometimes used, though perhaps with no advantage. Considering the great volatility of the metal antimony, we are disposed to believe that the process of reduction (*b*) by cyanide of potassium, as recommended by Mr. Mitchell, is superior to all others in the dry way. A mixture of four parts cyanide of potassium, and one part sulphide of antimony, being intimately mixed and heated in a porcelain crucible, reduction almost immediately ensues. The heat of a spirit-lamp flame, or of a few ignited pieces of charcoal, is suffi-

cient to promote the reduction. The low degree of heat required is, in point of fact, the greatest recommendation of the process. It will be noticed that in our statement of the means had recourse to for estimating the quantity of antimony present in an oxy-disulphide by the dry process, nothing has been said about the operation of roasting, so usually employed as the preliminary to the operation of melting, properly so called, when metallic sulphides are in question. By some operators the roasting of antimonial sulphide is advised: but this process cannot be recommended, seeing that the process of reduction is not difficult even without the preliminary process of roasting; and that when dealing with so volatile a metal as antimony, every process involving the loss of a portion should be avoided, except it be an actual necessity.

Bismuth.—Bismuth is a brittle white metal, presenting a distinct trace of redness, by which it is distinguished from zinc. Perhaps no metal so readily as bismuth assumes the crystalline state. If some of it be melted in a crucible, or ladle, and allowed to cool partially until a thin crust of consolidated metal covers the surface; and if now this crust be pierced, and the crucible or ladle inverted so that the bismuth which still remains fluid may escape; the central cavity, when opened by a chisel, will be found to present a congeries of beautiful crystals belonging to the rhombohedral system, and the edges and solid angles of which are exceedingly sharp and well defined. Owing to this crystalline tendency it is that bismuth is useful as an element of certain alloys used to receive and to impart well-defined impressions; for example, the alloy of which letter type and stereotype plates are composed. It also is a constituent of the solder by which articles of pewter are joined, and it enters into the alloys termed fusible metals; the fusibility of some of them is so low that they liquefy by the heat of boiling water, and can be retained in the molten condition in a piece of paper held over a candle. The geological localities of bismuth are few and circumscribed; nearly all the bismuth of commerce being derived from the mines of Schneeberg in Saxony. The ore of these mines is bismuth in the native or metallic state,—which condition, added to the low fusibility of the metal, renders the process of bismuth-smelting on the large scale more simple than the operation of smelting any other ore. The mere application of heat is required without the admixture of any flux; and the process is efficiently conducted in cast-iron cylindrical retorts.

Nevertheless, the bismuth thus immediately produced is not quite pure; it is contaminated with arsenic, iron, and traces of other metals, from all of which it may, however, be separated by fusion with a little nitre.

Native bismuth occurs in octohedrons (rhombic) belonging to the rhombohedral system. The peculiar reddish-white colour of these crystals is a striking mineralogical feature. Native bismuth is usually found in combination with ores of silver, zinc, lead, cobalt, and nickel.

Although native bismuth is the only commercial source of the metal, there are also brown sulphide of bismuth; silicate of bismuth; a mixed sulphide of bismuth, copper, and lead, constituting the ore known as acicular bismuth; tetradymite, a compound of tellurium and bismuth; native oxide, and native carbonate of bismuth.

Chemical Characteristics.

The most striking chemical characteristic of bismuth is its property of dissolving in strong nitric acid, and the solution yielding, when mixed with water, a white precipitate (subnitrate of the oxide of bismuth). It may be thrown down by hydrosulphuric acid as a sulphide, or by potash solution as an oxide. The latter being calcined in a porcelain crucible, and weighed, the chemist is enabled to determine the amount of bismuth formed; every 100 parts of oxide corresponding with 89·86 of the metal.

Furnace Estimation of Bismuth—The Bismuth Assay.

This operation is so precisely similar to the process already described as proper for the assay of lead, that no more explicit directions require to be given. Theoretically, no flux should be required; nevertheless, practically, a mixture of borax and black flux should be always employed.

Cobalt.—The peculiarity of cobalt in imparting a fine blue colour to borax, acted upon in the blowpipe flame, is so extremely characteristic, that the metallurgist will rarely have to gain the desired information by more elaborate means. This peculiarity may be impressed on the memory, if necessary, by reflecting that preparations of cobalt are the pigments used for imparting blue tints to ceramic ware. This metal, and also nickel, hardly belong to the category of mineral furnace assaying. The moist or laboratory processes of accomplishing their reduction and subsequent estimation are as satisfactory, though associated with difficulties, as the furnace methods are unreliable. To obtain a solution of cobalt unmixed with nickel, where the two metals are originally associated, is one of the most difficult operations of mineral analysis; but having once obtained a pure solution, the metal can readily be thrown down in the condition of oxide by addition of caustic potash, and the dried oxide can easily be reduced to the metallic state by heating it in a glass tube, through which a current of hydrogen gas is maintained. Cobalt solutions, the operator should remember, are not capable of precipitation by hydrosulphuric acid; they are, however, precipitated by hydrosulphate of ammonia. A similar remark applies to solutions of iron, manganese, and uranium.

Nickel.—This brilliant white metal, now so much employed in the manufacture of albata, or German silver, is chiefly obtained from the ore termed kupfernickel. It usually is a mixture of nickel and arsenic, but sometimes of nickel and antimony. The solutions of nickel are for the most part blue or green, somewhat in this respect resembling those of copper, from which, however, they may be disconnected by the circumstance of their non-precipitation by hydrosulphuric acid; and then yielding with ferrocyanide of potassium a bluish precipitate, whereas solutions of copper yield a precipitate which is of a mahogany brown colour. Nickel is determined, quantitatively, exactly like cobalt—*i.e.* by throwing it down as oxide by addition of potash solution, and subsequent reduction of the oxide by hydrogen and heat.

CHAPTER V.

THE DISCOVERY OF MINES AND MINING OPERATIONS.

The surface of our globe consists of an aggregation of mineral substances, varying both in their chemical and mechanical structure. Among these substances, what we have ventured to call the Useful Metals—designating under that term, Iron, Copper, Tin, Lead, Zinc, and some other alloys of these—are universally diffused over the earth's surface; either in the stratified or non-stratified state. In the former case, presenting regular laminated beds, or layers, at times horizontal, at others at a considerable angle with the horizon, and occasionally curved and irregular in their form; in the case of non-stratified formations, indicating a tendency to a crystalline structure, as if the mass had been fused, and allowed, by slow cooling, to group itself according to its natural affinities.

The terms Primary, Secondary, and Tertiary formations were formerly used by geologists to describe the rocks which form the crust of the earth; the first being applied to the crystalline rocks. To the sedimentary formations the term Secondary was long applied; but it was found necessary, as our knowledge of the earth's formation increased, to divide this class into nine groups—namely, transition, secondary, and tertiary; the first being applied to the lower stratified rocks, which contain traces of crystalline minerals, while the others embrace the more recent stratified formations. Modern science has, however, nearly superseded this classification, adopting a more minute and specific nomenclature.

In exploring a country for mineral veins, it is to be borne in mind that those ores which are most valuable in metallurgic operations, are seldom found on the surface; they are, in most instances, buried beneath the soil, and penetrate the solid rock, often to a considerable depth. Mineral veins are chiefly found, either in the primitive rocks or in the adjoining transition deposits; they are often nearly perpendicular in their direction, in which case there is little to induce the miner to follow them.

In the mining districts, there are certain technical terms in use which we shall have occasion to repeat, and which we shall here explain. The *lode* is the vein of metallic ore, which it is the object of the miner to obtain, and the rock in which the lode occurs is called the *country;* while the veins which are unproductive are called *cross courses.* The dip or inclination of the vein to the horizon is the *hade slope* or *underlie;* its intersection with the surface constitutes what is called its *run*, or direction. When the vein divides into smaller portions, they are termed *strings;* and when these veins become much attenuated, they are termed *threads.* In following the cavity which contains the lode, the two sides which regulate its thickness are

called the *walls*, the top being the *hanging-wall*, or sod; while the bottom of the bed is the *foot-wall*, or floor of the bed.

Local dislocations and misplacemeuts of strata are often found, which are here and there interrupted by fissures which have been filled up by mineral deposits. These fissures run across all the strata of the formations, intercepting the lodes nearly at right angles. They are rarely metalliferous; or if they contain mineral, it is rarely of the same kind as those occurring in the other lodes. These interceptious frequently produce faults or *slides*,—terms applied to the rock which fills the fissure, the rock being termed a *dyke*. The complications produced by *faults*, frequently impede most materially the operations of the miner. The mineral substance which constitutes the original lode, and the rock above and below, being often mixed together, the former thrown more or less out of its primitive direction by the sinking or upheaving of one of the walls of the more recent vein—the whole character of the bed undergoes a material change by one portion completely overlapping the other. As veins are most productive at, or near the points where these substances occur, the metalliferous mass on which the miner had been engaged is completely lost on comming to one of these cross veins, and it is frequently a work of great difficulty to recover it again. The first object to be ascertained in searching for the dislocated vein, is the direction in which the *wave* has taken place, whether to the right or to the left hand; from analogy the miner is generally enabled to arrive at a correct conclusion on this head. Continuing his level upon the cross vein in the direction he has chosen, if he has been correct in his calculations, the metalliferous vein will be again met with on the opposite side, when the level is continued as before. If the search requires to be continued for a long distance without success, he is probably at fault, and it will be necessary to drive in another direction until the vein is found. The faults which interrupt the coal beds are principally soft clay, mixed with boulders; at times of trap or porphyry.

The great coal-fields in the vicinity of Newcastle-on-Tyne, are covered by a thick layer of sandstone. On the south bank of the Tyne, there is a ridge which lowers the bed by 90 feet, whence it is raised in nearly a right angle about 80 yards above the surface by the fault, so that only the lower strata are visible. It sinks again 66 feet; and then runs almost horizontally to a tremendous fault which lowers the entire bed 280 yards, whence it gradually rises again. The same thing occurs in the coal-field at Ronchamp,in the department of the Upper Saone. These valuable beds are suddenly interrupted by a mass of porphyry in a direction forming a very slight angle. In the plains of Champagne, on the other side of the interruption, a continuation has been found of the red sandstone, which forms the roof of the coal-bed, and at a short distance the porphyry is again found; but not the coal-bed.

Experimental Works.—The existence of mineral beds or veins is usually indicated by observing attentively the fragments of ore carried down by the action of the running water. In following such indications, it is necessary to distinguish between heavy and light ores, between friable and

hard materials. Anthracite coal may be carried a great distance without losing much of its form, while bituminous coal will not go any distance without losing its peculiar characteristics; galena may be carried a great distance, but it is liable to be broken into small cubes by the action of the water. Useful iron ores are never carried far by the currents, being too tender for such transport. Tin ores are often found in alluvial gravel, bedded upon rock, and protected by layers of gravel; other ores are too friable to be carried by water, and too oxidizable to resist long the action of the oxygen of the atmosphere for any length of time. Where such specimens are found, therefore, there must be a vein at hand.

In the absence of other and more obvious indications of mineral deposits, but where, nevertheless, there are reasonable grounds to believe in their existence, excavation becomes necessary. The general direction of the lodes of the neighbourhood having been ascertained from the workings in other mines in the district, a series of pits are sunk at right angles to the run of the veins. This, in the language of the Cornish miner, is called *shodeing* or *costeening*, and the pits "shode-pits:" terms which will be described presently. Having ascertained the existence of a vein of mineral, the next point for consideration is the nature of the ore and its value. For this purpose it must be assayed for its quality, and if possible this should be in the smelting-furnace, and on a scale of sufficient magnitude to afford a fair test of its quality.

As in Devon and Cornwall more extensive mining operations for obtaining metallic minerals are carried on than in any other district of similar extent in the world, the practice adopted there may fairly be taken as a standard for operations elsewhere. Indeed, the Cornish miner is usually sought for as the guide and manager in all foreign mining adventures undertaken by British companies.

The discovery of suitable localities for mining operations is effected in various ways. Tin and iron ores are more commonly discovered by shodeing; copper, lead, and sometimes tin, by costeening. Wherever granite occurs in the neighbourhood of killas, kellas or clay-slate, the presence of metallic minerals, principally copper and tin, in veins running east and west, or nearly so, may be expected; when at a distance more remote from the granite, and in veins running north and south, or nearly so, minerals containing lead may be expected. Supposing a stone, containing tin, which is easily recognized by its superior weight, to have been discovered in a valley, or on the side of a hill, it would be termed a shode-stone; and a search undertaken to discover its original site would be termed *shodeing*. Of course, if found on the side of a hill, it would fairly be presumed that it had been washed there from a point higher up; therefore, according to the contour of the hill, the search should be directed. It is not always necessary that the shode-stone should contain the metal actually sought for; it may be sufficient to have found the most common companion of it. Commencing at the original place of discovery, similar stones are sought for, and will be found more and more numerous as the lode from which they were originally poured forth is

approached. The term shode is derived from *schutten* (Teutonic), to pour forth. The lode having been reached and passed, all appearance of shode-stones will, of course, disappear, and the miner's steps must be retraced. The vicinity of the lode having been ascertained, the lode itself is identified by sinking a few shode-pits in order to discover from the stratum or shelf immediately below the soil, or *meat* earth, surer indications of its proximity. It rarely happens that a lode is found in a perfect state close to the surface.

A perfect lode should present the appearance of a fissure in the rock, containing, between two distinct walls or faces, deposits of earthy and metallic minerals differing entirely in character from the rock itself, and principally characterized by the constituents presenting a more or less crystalline form. Instead of this, the prolonged action of water and atmospheric agencies appears to have caused more or less the decomposition of the lode, and of the containing rock or *country*, which have been broken up and mingled together; and thus has been produced the bryle or broil of the lode, from which the shode-stones have rolled away, and the discovery of the lode itself brought about, as shown in the annexed engraving (Fig. 1).

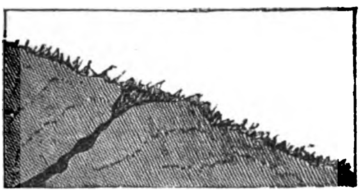


Fig. 1.

The older miners declare that the search for shode-stones, in some instances, has originated, not with the finding of a stone of ore, but from certain appearances of dancing lights, or *burning drakes* as they are called, resembling will-o'-the-wisps, which have been repeatedly observed at intervals over a particular line of country. Although we cannot at present account for these phenomena, such observations are worthy of being registered, seeing the important discoveries now being made in the relations existing between magnetism and voltaic and frictional electricity, which may throw valuable light upon such observations, and render them of practical utility.

It is believed by many of the most intelligent mining adventures in Cornwall, that some of the most valuable mines in the county have been discovered through the agency of the *vulgua divinatoria*, the divining or dowseing-rod. This instrument is composed of two pieces of hazel-twig tied together with pack-thread or twine, the root-ends being brought together, and the smaller being held in the hands. Hazel-rods, cut in the winter and dried, are said to answer best; but apple-tree suckers, or twigs of peach-tree, plum, currant, willow, or oak, even if green, will answer tolerably well. If tied with silk, worsted, or hair, it will not act. The rod is said to act in any hands, but much more energetically with some than with others.

The land to be examided is *explored* by the dowser walking slowly over it from north to south, holding the rod in his hands; not perpendicularly, but at an angle of 70°. When approaching the lode, the rod feels loose in the hands, and is repelled towards the face; on being brought to its former position it is again repelled, until the foremost foot is over the lode, when it

will be irresistibly drawn down; and in this position it will continue until the lode is passed over, when the repulsion will be again perceived. Most of our readers will remember the "divining-rod," and the German adept Dousterswivel, so admirably delineated in the "Antiquary," and marvel to find the superstition gravely repeated in our day as one actually practised.

The distance between the point of appearance and disappearance of the depression, indicates the thickness of the lodes. The course of the lode may also be traced by walking in zig-zag lines over it. This method of discovering the course of lodes, if in practised hands, is indisputably of great practical value, and renders efficient service where shodeing cannot be adopted, for all lodes or veins are not alike effected by the agencies already referred to, some of them remaining comparatively unaffected, and producing no shode-stones. A more certain plan than that of sinking shode-pits at intervals, is to drive a cutting open to the *grass*, two or three feet through the shaft; thus all the lodes within the bounds of the exploration may be at once discovered.

The place of the lode having been discovered by shodeing, it is necessary in the next place to determine the line in which it runs; and this is most commonly done by costeening—that is, by sinking pits down to the rock at such distances from each other as to verify the supposed direction of the lode. This term is derived from *Cothas stean* or dropt tin. The locality and direction of a lode has not unfrequently been determined by the peculiar appearance of the herbage covering the surface; sometimes by the colour of the freshly-ploughed soil; or by the character of the water issuing from adjacent springs. The sinking of wells, the cutting of roads, excavations of races for water-wheels, the accidental exposure of the rock from the washing of the sea or of fresh-water streams, and the occasional washing of the pebbles from the sea-shore, have been among the most common means of discovering mines. In the neighbourhood of Tavistock, some valuable mines were discovered in cutting a tunnel for the canal from that town to the banks of the Tamar. Sometimes in driving adit-levels for the working of a new mine, lodes are cut into much more valuable in their produce than the one which originated the work, but of which no trace had ever presented itself at the surface. A lode or series of parallel lodes having been discovered, and the character of their mineral contents satisfactorily ascertained, it is necessary, before determining to commence mining operations, to consider the locality and resources of the district; whether sufficient water can be obtained for dressing the ores, and driving machinery; and whether the roads or other means of conveyance will allow of the necessary materials being obtained for working the mine, and of the ores being conveyed to market at such a cost as will admit of profit. These are all considerations to be borne in mind before commencing operations.

As lodes frequently extend many miles, the discovery of the combinations of a lode on which a celebrated mine may have been successfully worked, is often regarded as sufficient inducement to incur a very large outlay of capatal in its exploration: even without the ore having been found, or any other indication than that of a kindly gozzan or gossan, which is com-

monly a spongiform mass of quartzose stone, containing loose ferruginous coatings, the probable remains of decomposed sulphurets of copper and iron. Sometimes a sprinkling of crystals of mundic or iron pyrites may be observed; and on chemical analysis, traces of copper may be discovered.

For a long time it was held that copper could not be found in quantites to pay, to the eastward of Truoro bridge. The prevalence of this crude notion tended long to confine explorations for the ore of this metal; but the rapid development of mines of the most important character throughout the eastorn part of Cornwall, and the western districts of Devonshire, have given miners greater confidence in applying the principles of mining to the exploration of new districts, instead of adhering to old localities simply on account of their acquired character and ancient traditions.

The direction of the lode having been ascertained, it is in the next place necessary to determine the direction and amount of dip or underlie of the lode—whether it be from north to south, or *vice versâ*; also how many inches or feet per fathom it is out of the perpendicular in its descent. According to the character of the ground, or *country*, it is to be determined whether to sink a shaft, or to drive up an adit-level from the nearest valley, so as to cut the lode at twenty, thirty, or forty fathoms from the surface, and thus at once to ascertain the quality of the lode. If the ground be easy to sink through, it may be considered best to sink at once a shaft, because, as it goes down, it affords the opportunity of setting a greater number of men at work at different levels, as may be seen from the annexed sketch (Fig. 2). As soon as the shaft is, say, twenty fathoms in depth, the driving of a level to crosscut the lode at *a* may be commenced; at thirty fathoms the lode itself may be cut and sunk through, passing on to another ten fathoms in depth. By driving an adit-level, as at *b*, to cut the lode, less machinery will be required, as the water, which is the principal difficulty the miner has to contend with, will run away of itself; and thus although it may be necessary to excavate a very much larger quantity of ground to reach the lode, it may be, and indeed generally is, less expensive to cut the lode, by driving the adit-level, than to sink the shaft. This is more especially the case, seeing that even after the lode has been cut by the shaft, the adit-level will be necessary to run off the water, if further operations be determined on.

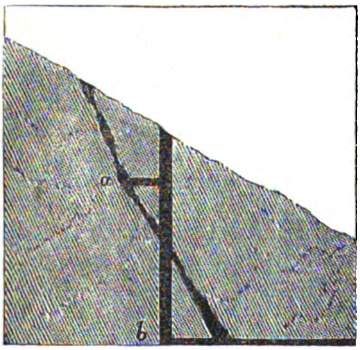


Fig. 2.

The sinking of the main or sump-shaft, and the driving of the adit-level, are the two most important operations in mining. The object of the former is to provide access to the lode at different depths, for the conveyance of labour and materials, for the extraction of the ores, and for the removal of the

water by machinery. The object of the latter is to provide for the removal of water by preparing an outlet for it at the lowest possible point, so as to prevent the expense necessary for lifting it to the surface of the mine by means of pumps.

If the main shaft of a mine be 100 fathoms in depth, and there be an adit-level at 40 fathoms, the water will have to be lifted only 70 instead of 100 fathoms. By the co-operation of many mines a great permanent saving of expenditure may be effected by directing the adit-level of each mine into one main adit, by which it may be made to serve instead of having a separate one for each mine. By reference to the annexed diagram (Fig. 3) this arrangement will be easily understood.

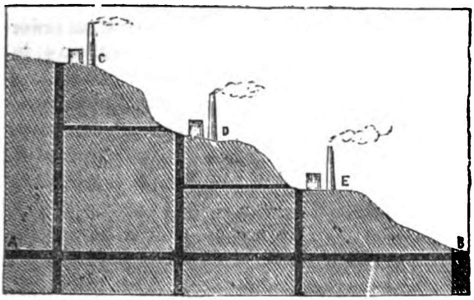


Fig. 3.

Supposing a district of some miles in extent to be here represented, A B will be the main adit, C D E three mines at different elevations, E having driven up a main adit from B to E, its own main shaft; by a continuation of it to the shafts of D and C, these two mines will be able to discharge their water at the level A B instead of at D and E.

The advantages of this method of working are well shown at the United Mines near Redruth, where a main adit has been driven between four and five miles in length, into which branches from between forty and fifty mines have been opened. It is carried from a point only a few feet above high-water mark. With all its branches, its extent is between thirty and forty miles. Its greatest depth from the surface is seventy fathoms, but the average is about thirty fathoms. By this work the expense of machinery, and of coals necessary for lifting the water of all these mines thirty fathoms in height, which has been calculated at 24,000 tons of coal per annum, are saved; so that for coals alone a saving has been effected of £19,000 per annum, This magnificent undertaking was commenced in 1748, and completed in 1768.

The sinking of the main shaft, and the driving of the adit-level, may with advantage be conducted at the same time; for it not unfrequently happens that the adit-level draws off much of the water that would otherwise have to be raised to the surface; it also affords the opportunity, after it has been driven up to the point under the sinking shaft, of setting *pairs* or *cores* (corps) of men at work to expedite the formation of the shaft, by rising up towards the men at work above. This, of course, can only be done where the ground is sufficiently compact; but if this cannot be done, the adit-level having been driven up to the lode, two different sets of men can almost immediately be set at work upon the lode right and left to extract its contents. Where the mine is rich in metallic ore, it may immediately become pro-

ductive of profit. Frequently adit-levels are used not only for the drainage of the mine, but also for permanently working as a tunnel for the extraction of the ores without any main shaft.

When this is the case, the level is made larger to provide for the permanent traffic over the tramway laid for running the waggons in and out of the mine. This tunnelling is commonly driven through rock or *country* sufficiently solid to support itself; but where the ground is soft, it is most commonly supported with timber, more rarely with masonry. The work of the miner in driving an adit is comparatively simple, consisting principally of pickwork, boring and blasting with gunpowder, and removing the attle or waste in wheelbarrows or waggons. When the level is being driven, in order to meet a shaft, these simple operations have to be conducted with care, in accordance with the directions of the superintending *captain*, who marks out the course to be followed by carefully dialling the ground; for this purpose he employs a theodolite mounted over a large mariner's compass. The most careful dialling is required where an adit-level has been driven forward to the point below a shaft in course of sinking, and it has been determined to work upwards to meet the miners sinking.

As it is of the utmost importance that the main shaft should be perpendicular on all four sides, in order to produce perfect work, both parties must be working round a common central perpendicular line, which, however, cannot be determined until a communication is opened between the sinking and the rising miners. Although the operation requires great care, it is very seldom that any error occurs. The size of the main or *sump* shaft of a mine is determined by the purposes for which it is intended to be employed. More commonly it is used only for pumping up the water, but it is also sometimes used by being parted off with timber into compartments for footway purposes, and for the raising of the ores. As it is sunk, at least in the upper part, it is always carefully timbered; but frequently in depth, the ground or country becomes sufficiently compact to render this unnecessary. As soon as the sinking of a main shaft is commenced, it is necessary to erect a *count-house* and store for materials, a powder-house, and a carpenter's and blacksmith's shop. At first a common windlass and a pair of buckets are used, worked by hand, for bringing the water and rubble to the surface or *grass*; but while the sinking is going on, a perpendicular windlass or whim is erected for the application of horse-power, so as to lift about three hundredweight at a time in iron buckets or kibbles. As the deepening progresses, the water increases, sometimes so rapidly that the labour of the miner is of necessity suspended until the aid of the steam-engine or water-wheel can be obtained.

Mining Operations.—The square form of the shaft, while it absorbs more timber, and is of a weaker section than the circular, affords great facilities for timbering up weak places. This is done by a series of close vertical timbers, maintained in position and strengthened at intervals of a few feet by interior frames, made of logs of Norway timber. The quantity thus annually consumed in mining, in Cornwall and Devon alone, is estimated to amount to a million and a half cubic feet. For fifteen or twenty fathoms, a wooden wind-

lass, wrought by hand, serves to draw up the broken material and let down such articles as may be required.

Below this, the sinking is prosecuted for a few fathoms by a horse-whim, or gin, as it is termed in the northern districts. The sinking of a shaft through hard ground, is a tedious and costly operation. When prosecuted day and night continuously, a few feet is all that ten or twelve men can penetrate in two months. The outlay, under such circumstance, often amounts to £50 or £60 per fathom. Gunpowder is in constant requisition to dislodge the rock, which not unfrequently is so hard as to require the entire quantity to be blasted, a small fragment at a time. The tools used by the miner are not numerous, comprising the heavy steel-pointed pick, shovel, wedges, or gads, chisel, or bowyers (borers), hammer, and the small instruments required in drilling. The operations in sinking are principally confined to drilling the rock and blasting, disposing the charges of powder in such manner that the effects of successive blastings shall carry the shaft down the required dimensions without largely employing the wedge and pick. This is done by drilling at the bottom of the shaft, in such a manner as shall clear away the largest amount of obstructive rock, with the greatest economy of labour and material. The broken ground is filled into iron buckets, or kibbles, and drawn to the surface. A sketch of the horse-whim by which this is generally done in shallow mines, is appended in Fig. 4.

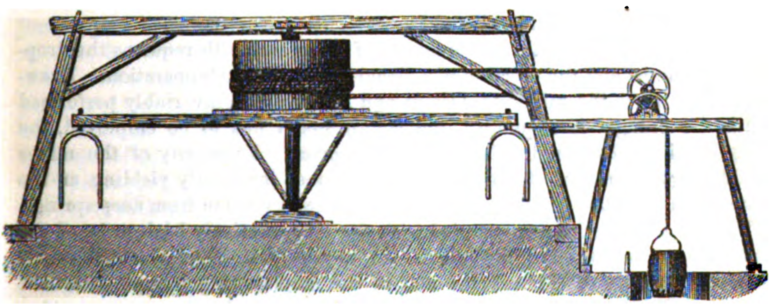


Fig. 4.

The chisel for drilling rocks consists of a steel-pointed bar, one to one inch and a half wide at the point, and three to five feet long; this is held firmly in the hand by one man, and struck on the head with the hammer by another; between each blow it is turned partly around, to clip off a fresh bit of rock. Lately, with great economy of material, the borer has been made entirely of steel. If the rock is of medium hardness, an hour or two suffices to drill it to a depth of two or three feet. In the hardest rocks, the same number of inches is a common rate. Water is used in some districts to facilitate the action of the drill; in others the operation is a dry one. When drilled to the required depth, the hole is dried with some fine clay tightly rammed down by a bar, or by wads around the cleaning-rod. The charge of powder is now

carefully conveyed to the bottom, and the point of a copper needle-bar, reaching along one side to the top, placed in contact with it. On the powder the tamping is laid; this consists of any convenient material sufficiently hard to bear heavy tamping, yet of such a nature as not to strike fire with the bar used. The needle is now withdrawn, and a rush train laid in communication with the charge. Rushes are prepared for the purpose by splitting down one side, extracting the pith, and filling the interior with fine powder; when the sides close and secure it by their elasticity. The length, including the portion in the hole, is required to be such that after lighting it, the burning down to the charge shall afford ample time for the workmen to reach a place of safety. Commonly the men contrive to have several holes ready about the same time, and by setting fire to the trains simultaneously, economise time. If from any cause a hole misses fire, it should be abandoned, and drilled again out of contact with the old bore. Picking out, even with a copper needle, is at best a dangerous operation.

Of late years the risk of hanging fire through damp and imperfect fuses has been greatly diminished by using canvas cartridges payed over with boiled pitch and caoutchouc. Gutta-percha also has been employed for the same purpose; and though an expensive material, for wet shafts it is an invaluable acquisition to the miner. Water-proof safety fuses in long lengths are now used throughout Devon and Cornwall, to the entire exclusion of the rush and straw fuse, which have rendered the occurrence of accidents from the premature explosion almost unknown.

At considerable depths, the quantity of water met with requires the dropping of pumps and the erection of a steam-engine for their operation. Drawing water from the mines in Devon and Cornwall is invariably performed with the plunger force-pump; and where steam has to be employed, the single acting steam-engine is the motive power. A majority of the mines yield large quantities of water; the larger ones frequently yielding at the rate of 2000 or 3000 gallons per minute, the greater portion from deep springs. This large yield of water, coupled with the comparatively high price of the fuel used under the engine-boilers, led to the attainment of considerable efficiency twenty or thirty years ago in the single-acting pumping-engines. By carefully clothing the boilers and steam-pipes, and using to a considerable extent the expansive action of the steam, the consumption of coal under the boilers was reduced to two or three pounds per horse-power per hour. Steam-engines in other districts were at that period using large quantities of fuel, in some instances twenty pounds the horse-power: lately, great improvements have been made in these engines, and a consumption of fuel not greater than prevails in Cornwall is very common. Taking engine and pump-work together, however, though the erections are often of a temporary character, the system of unwatering the deep mines of Cornwall is immeasurably superior to that pursued in the midland and northern districts.

The force-pump employed consists of a cast-iron plunger turned on the outside, and fitted inside with a single piece of pine, which projects at one end sufficiently to attach it by numerous clumping-bolts to the main pump-rod;

the plunger works into a cast-iron barrel, of one or two inches larger diameter, through an air-tight stuffing-box at top. At the bottom the barrel communicates with boxes containing inlet and outlet valves. Admission of the water to the plunger case is obtained through a perforated pipe ("windbore" of the Cornwall, "snore-pipe" of the Welsh miner), in order to filter the water of any substance likely to impede the action of the valves. These are sometimes made of leather, strengthened by a pair of iron plates, for short lifts; but plungers forcing a high column, are now generally fitted with compound metal valves, bearing on soft metal rings. Since a column of water presses with a force of one pound to the square inch for every twenty-six inches of height, the augmentation of pressure within the lower pipes places a limit to the height which one single plunger and one set of cast-iron pipes are capable of safely delivering the water. Eighty yards may be considered a high lift for one plunger; where the water has to be lifted higher, the total height is divided between two or more force-pumps, working off the same main-rod, the lowest set delivering the water into a cistern for the next in elevation; and so on. This is the system pursued in the deep Cornish mines, where may be seen eight or ten pumps in depth, each lifting the water to the height of its division of the shaft, and actuated by a common rod from the engine. With a lift of eighty yards the plunger case, valve boxes, and lower tier of pipes, work with a pent-up pressure of nearly 110 lbs. to the square inch.

In very many mines the acidity of the mineralized water acts most injuriously on the metal with which it may come in contact. To prevent their speedily becoming unserviceable, the pump casings, boxes, pipes, and parts of the well work of the engine, are lined with wood. The arrangement of the pump, rod, pipes, and connections of a lift in a large shaft, form most important features in many operations; but these belong so exclusively to mechanical engineering, that we must not dwell further on the subject here.

The explorations on the lode are usually commenced on attaining a depth of twenty fathoms, or sooner if its metalliferous character seems to warrant its removal. This is done by driving a short cross-cut to the lode, and proving its character by driving a level in each direction with just sufficient rise to drain freely to the shaft. If promising a fair yield of ore, these levels may be prosecuted a considerable distance. In estimating the richness of a lode, miners are accustomed sometimes to give its width, and the number of tons of ore per fathom which it yields in driving the level; at other times the money value to the proprietors. Meanwhile, the sinking of the engine-shaft is continued, and ten fathoms' deeper communication is again made with the lode and level driven on it; these are prosecuted according to their presumed value. Communication is also opened at regular intervals between the levels, by means of small shafts termed "winzes." By the horizontal levels and vertical shafts at set distances apart, the portion of the lode explored is cut vertically into a number of square blocks. At each succeeding ten fathoms, similar communications are made, and levels driven to prove the value of the lode. In a well laid-out and fairly managed mine, the sinking of the shafts and prosecution of the levels are conjointly carried on to an extent

sufficient to develop its riches, and cause a progressive increase in the quantity of ore ground exposed.

The sinking of shafts, driving of levels, and work of a similar nature, is called "network," and is undertaken at per cubic fathom down or forward. The contracts are for two months, when they are again re-let at Dutch auction to the lowest bidder for a further term of two months, with a strict or limit of extent of work, to provide for an alteration of character of ground from difficult to easy work. This competition system results in the work being performed on very economical terms. The price paid includes all expense, save drawing of the water; the costs incurred for iron, steel, smithwork, powder, fuses, and tools generally, and for drawing and removing the material cut, are deducted from the sum accruing at the letting price.

The extraction of the ore is principally performed by a class of contractors called "tributers," who in pairs or cores of from two to eight or ten men and boys, undertake the working of a piece of ground on condition of securing a stated proportion of the proceeds of their ore. The miners' share varies with the apparent richness of the "pitch" or block of ground which they have taken. If the lode is rich and easy to work, sixpence or a shilling in the pound may be the tributer's portion; if of average richness, he will have four or five shillings; a poor lode in hard ground lets at from ten to thirteen shillings in the pound sterling, and at this high proportion may scarcely afford a bare living to the tributers. The contracts for the extraction of the ore are submitted to a similar auction and competition amongst the miners as the network, the lowest bidder having the contract. To prevent collusion amongst the assembled men, the agents place a reserve price on each contract, which is afterwards opened, and the miner has the option of accepting the lesser price or throwing up the contract.

The ores broken by the tributer are filled into iron tram-waggons, running on rail bars, and conveyed by boys to the shaft, where they are removed into buckets, or kibbles, and drawn to the surface. Iron buckets with single-line chains are generally used in drawing the ores, but of late years a few shafts have been fitted with boxes suspended by flat hempen ropes. These ropes are made by sewing together four or six small round ropes, with the twist laid alternately in each direction. At the top of the shaft the contents of the buckets are transferred to another tram-waggon, and removed to the dressing floors.

It may be observed that in bringing the ores to the surface from deep mines, the apparatus used in Cornwall is greatly inferior to that in use in the Welsh and Newcastle coal districts. No perceptible improvements have been made in this department within the present century, though ample room exists; and the introduction of the modes practised in other districts unquestionably would greatly diminish the cost of drawing the ores. The substitution of steam for human power in letting down and adjusting the ponderous pumps and rods, though practised for some twenty years in Wales, has only been adopted in Cornwall within the last three or four years.

Descent to the Mines.—Access to the underground workings is ob-

tained by narrow ladders placed in the large or sump-shafts, or in smaller ones termed footway shafts; very frequently they are placed nearly perpendicular, and accidents from falling off are common. In addition to the direct loss of life by accidents, the waste of life and labour in the toilsome ascent from the deep mines after the day's labour is very much greater than is commonly supposed. If we estimate a miner to weigh with his dress and accoutrements 186 lbs., and the ascent to be made from a depth of 200 fathoms below the surface—not an unusual circumstance, since several mines are more than 300 fathoms deep—the muscular power exerted during his ascent is equal to the lifting of one hundred tons one foot high. This is not an extreme case: many men do more. Taking the whole of the mines, and their medium working depth, it will be found that the miner's strength is taxed to the extent of lifting fifty tons one foot high in order to place himself on the surface; and from the mine he may have to walk two or three miles to his dwelling; but this portion of his labour, of course, forms no part of the defects of the mining system.

An attempt has been made to remedy this waste of labour; but the defective way in which it was made has prevented more than one or two applications of machinery to the purpose, The plan adopted (in three or four mines only, out of as many thousands) consists in suspending wooden rods at the end of a working beam capable of communicating a stroke of twelve feet; either one or two rods being used. Secured to the wooden rod are small platforms, the length of the stroke apart, of a size sufficient for the standing of two men; on a second rod, or secured to a standing timber (Fig. 5), are corresponding platforms, which are directly oppositite those on the rod when it is at the bottom and top of its stroke. If two rods are used, the connections are so made that the weight of one, balances that of the other, The operation of the machine is very simple: a man standing on the upper platform descends twelve feet with the down-stroke of the rod, and steps on to the opposite platform; if a single-rod machine, he here waits the return down-stroke, and getting on the second platform, descends a second twelve feet. This changing from the fixed to the moving platform, and *vice versâ*, is repeated until the required depth is attained. With two rods the time lost in waiting does not occur: by stepping from one to the other, he descends in half the time. The ascent is made by going on the platform when the rod is at its lowest stroke, and continuing this order upwards. Steam or water-

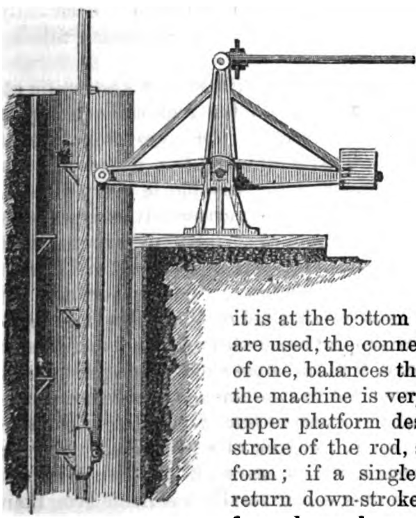


Fig. 5.

power is required to maintain the machine in motion during the day; but if well balanced and unnecessary friction is avoided, the power absorbed is not great.

The great defect of the apparatus, and to every appearance an insurmountable obstacle to its general adoption, is its great cost. It is, in fact, so costly that very few, even of the highly remunerative mines, can afford to expend so much capital. In a commercial point of view, even the uncertainties of mining are such, that a positive evil of great magnitude is endured because the proprietors know not how long it may be advisable to prosecute the mine. The prospects of the mine may in a few weeks alter to such an extent as to cause its abandonment.

To the experienced coal and iron-stone miner, the whole of the Cornish system of drawing ores, and ascending from mines, appears rude and barbarous in the extreme; it is only one step removed from the notched tree of the savages of the Southern Ocean. The mines of the continent are nowise superior; yet the capital expended on this rude system is much greater than is laid out on the most highly-finished coal-pit apparatus, which combines in one a safe and rapid conveyance for the miner to and from the surface, and an infinitely cheaper method of drawing the minerals. A system which forces men to climb hundreds of fathoms daily, in addition to their ordinary labour, ought no longer to exist. Doubtless the force of example will eventually lead to the alterations required to raise this part of the Cornish mining system to a level with other districts.

Ventilation of Underground Workings.—Hitherto few systematic attempts have been made to supply the miner with the requisite quantity of atmospheric air, and the consequences are seen in the large proportion of fixed air in a moiety of the workings. This inattention to a matter of such vital importance to the health of the miner, is inexcusable in every respect. A current of atmospheric air is conducted through narrow tortuous passages of several miles in extent, with such facility and at such triffling expense, that no reason can be adduced why one-half of the miners in Cornwall and Devon should be working in a highly poisonous atmosphere. To a miner from the midland or northern districts, the apathy exhibited on this point is remarkable. In no part of the world where mining has been prosecuted can greater indifference be seen. The movements of the drawing and pumping apparatus produce triffling currents in the shafts: but the workmen at the extreme ends of levels, the bottoms of winzes, and the adjacent pitches, are left to the surrounding stagnant air. This acts on the organs of respiration, producing consumption and other allied diseases, which carry off the miner in the prime of life. As a class, thep are robust and naturally less liable even than seamen to such diseases: but such is the pernicious effects of the impure air they breath, and the barbarous mode of ascending from the bottom, that fifty-two per cent. die of consumption in a county where the per-centage amongst agricultural and other surface labourers amounts to twenty in the worst localities. Seventeen per cent. of the miners meet with a violent death from accidents in mines. At a moderate computatation, nearly 500 lives

are needlessly sacrificed annually from one disease only. Its insidious advances on the constitution are commonly unperceived by the miner, who reluctantly abandons the unventilated mine, and finally succumbs to its influence unnoticed in a county where human labour and life are valued at a very low rate. Compared with this wholesale waste of human life, the loss from accidents and explosions in coal mines, with ten times the number of miners, is perfectly insignificant.

Nor is this the only waste of life in the Cornwall mines. From a false spirit of economy, the dressing operations are performed principally by young femals, stationed in open sheds, or altogether exposed to the inclemency of the weather in bleak districts. Amongst these, consumption is scarcely less prevalent than amongst the miners; while the mass of disease transmitted to their posterity is too painful to contemplate.

The absence of ventilation seriously operates against the economical prosecution of several mines; the miners are unable to stand the usual number of hours, frequent relays are required, and the ultimate outlay is augmented in a greater ratio than the number of men employed. Instances have occurred where the sum offered for driving levels without ventilation, has been ten times the value of the same work with pure air, and this in places where the hundredth part of the excess of price judiciously applied, would have caused an abundant supply.

With these few remarks on this all-important subject, we shall leave the exposition of the mechanical and legislative remedy for these evils to one who has established for himself a claim to be heard on the subject.

CHAPTER VI.

MINING JURISPRUDENCE AND VENTILATION.

The economy of time and of labour is the object of all manufacturing improvements which aim at cheapness of production; and, collaterial with these, is now recognized, as an essential co-efficient, the economy of human life. Where the demand for labour in any special occupation is small as compared with the supply, a slight addition to the wages will suffice to attract workmen, although more than counterbalanced by the exhaustion of strength and deterioration of health which commonly result, when the animal functions are unduly taxed; but in any great development, such as coal and iron mining have undergone in the last twenty years, the demand and cost of labour are greatly enhanced by the more rapid wearing out of the labourer. To render labour possible far beneath the surface of the earth, much attention to the condition of the workshop is required; even to avoid unnecessary danger, and to secure the full yield of work for a given expenditure of time and labour, such provision must be made as will maintain the health and vigour of the workman unimpaired.

It is by the changes in the air that the operations of the miner are chiefly retarded; the laws of ventilation assume, therefore, a prominent position in the economy of mining. A miner excavates a tunnel or space before him, sufficiently wide to allow himself room to work and progress in the cheapest manner. This excavation serves a threefold purpose—for the extraction of the minerals by means of barrows or trams; for carrying off the springs of water met with; and for supplying the miner with atmospheric air sufficient to keep his candle burning. The room in which he continues to work, expands in form and size, according to the position of the minerals which he finds it remunerative to extract. In thin seams of coal, less than eighteen inches is sometimes the whole height extracted; here the miner, whilst working with the pick, lies on his side. In sinking shafts or driving galleries in a rock, the work is chiefly blasting; and, in a more or less stooping position, the miner plies his drill and hammer to bore into the rock. In "rising a winze,"—*i.e.*, making an air-shaft upwards—and in "getting" nearly vertical metalliferous veins, much of the work is performed overhead. In such veins, the roads or galleries by which the minerals are brought out from the working parts, vary generally from five feet high and three feet wide, to seven feet high and five feet wide; but the height is ordinarily governed by the inclination and thickness of the productive strata, and the strength of the superincumbent rock In many coal-mines, it was a custom, now happily becoming rare, to perform the underground haulage in the height of three feet, by means of boys having harness round their hips, who were employed to draw the tubs—unquestionably the most expensive means of transport that could be devised. Forty-two inches is the lowest gallery in which ponies are substituted for boys; and in this height, numbers of Shetland and Highland ponies may be seen working in the North of England coal-mines. The height of the roads materially increases the facility of ventilation. As the mines increase in depth, the roads or galleries can only be reached by sinking shafts from the surface. The sizes of these vary from three feet up to twenty feet in diameter; and at the Tresavean mine in Cornwall, the depth attained below grass was 750 yards. There are four distinct portions of a mine which have to be considered in relation to the ventilation,—the shafts, the underground roads or galleries, the working places at their extremities, and the old workings (technically, deads or goafs). These are all distinguished from other workshops by the peculiarities of temperature, pressure, moisture, and composition of the air—by the gases and miasmata which exist in them—by the absence of sunlight, and the mode of lighting—quite as much as by the motions and working positions of the miners, which differ from those used in any other occupation. In the deeper parts of his workings, the miner is liable to be stopped, or overwhelmed, either by water or carbonic acid: in the higher parts he may be suffocated or destroyed by irrespirable and explosive gases; and if he enters but a very short distance beyond the point for supplying the necessary amount of atmospheric air, it becomes deteriorated to an extent injurious to life.

The average composition of the atmosphere is, for each thousand parts—nitrogen, 788; oxygen, 197; vapour of water, 16; carbonic acid gas, 1.

The proportions of nitrogen and oxygen are maintained with singular exactness on every part of the surface of the globe, even in the highest regions yet reached by man: a certain indication, it may be deemed, of the necessity of such a provision to the maintenance of animal and vegetable life. Professor Graham determined that the diffusiveness of each gas approximated to the inverse ratio of the squares of its density: thus the relative capability for the diffusion of air, nitrogen, oxygen, and hydrogen, would be as 10, 10, 9 and 38; but subjected to such action alone, without the influence of the wind and other atmospheric currents, the composition of the air could not be maintained.

The air of a mine becomes rapidly deteriorated by chemical combinations of various kinds. Strata of air, carburetted hydrogen, and carbonic acid gas, are frequently met with in mining operations; the diffusion proceeds very slowly, and an active current of pure air is required to mix with and dilute them. The breathing of the men and horses, and the products of combustion of the lights, abstract oxygen, and evolve carbonic acid gas, nitrogen, and aqueous vapour. Oxygen is also absorbed by the decomposition of various mineral substances, especially sulphurets and protoxides, acted upon by water; and by the decay and fermentation of timber and animal matters, which accumulate in underground workings. Various compounds of carbon, hydrogen, and sulphur are thus thrown off into the air of the mine. The nitrogen which is found mixed with the carburetted hydrogen exuding from the pores of coal seams, and the formation of carbonic acid gas in most coal-mines, are evidences that the coal undergoes decomposition, which assists in impoverishing the air of its oxygen.

The annexed table represents the specific gravity of the various gases, and the relative positions they usually occupy.

Names of Gases.	Spec. Grav.	Cub. ft. in 1 lb.
Hydrogen	·069	189
Carburetted Hydrogen	·55	24
Steam at 212°	·62	21
Carbonic Oxide	·972	13·4
Nitrogen and Miasma	·976	13·4
Olefiant	·98	13·3
Air	1·00	13·06
Oxygen	1·10	11.9
Sulphuretted Hydrogen	1·19	11
Carbonic Acid	1·52	8·6
Sulphurous Acid	2·12	6

Among other products injurious to the miner's health are the uncombined carbon arising from bad candles or from lamp-oil, the miasmata arising from perspiration and animal exuviæ, and from the smoke of the powder used in blasting. Carbonic acid, carburetted hydrogen, carbonic oxide, nitrogen, and sulphuretted hydrogen, together with compounds of sulphur and potassium, forming the smoke, are the products of the last operation. The effects of the powder smoke, when not carried away by active ventilation, are such as to prevent the miner from resuming work for a space ranging from several minutes up to half-an-hour after a shot is fired.

The effects of breathing in a confined space are readily appreciated in a mine: the miner's head is near the roof, where the heated gases stagnate to an extent sometimes sufficient to extinguish a candle, although it would burn freely if placed on the floor of the mine, a few feet below. The action of breathing may be appropriately termed the ventilation of the blood. The expansion of the chest, by the powerful muscles appropriated to the action of the lungs, produces a partial vacuum sufficient to inhale a portion equal to about one-tenth of the air already contained in the chest. Aided by the circulation caused by a rapid change of temperature, the oxygen is brought into contact with those delicate labyrinthine tissues (the surface of which is variously estimated at from fifteen to four hundred square feet), where the oxidation of the particles of blood is effected. The average of a number of experiments by Vierordt, Liebig, and Lehmann, gave 320 cubic inches as the quantity of air inhaled per minute; of which 10 per cent., consisting of oxygen, are consumed by the lungs, and 7·7 to 8·5 per cent. of carbonic acid gas, besides aqueous vapour, are expired. The weights and quantities are thus given by Dr. Reid:—Time, 1 minute. Number of respirations, 20. Air inhaled: volume, 320 cubic inches; weight, 99·24 grains. Oxygen consumed: volume, 32 cubic inches; weight, 10·94 grains. Carbonic acid discharged: volume, 25 cubic inches; weight, 11·82 grains. Carbon evolved: weight, 3·27 grains. Oxygen in carbonic acid, 8·55 grains. Oxygen unaccounted for by weight, 2·40 grains. Watery vapour: weight, 3·20 grains.

The oxygen inhaled produces a slow combustion, and the oxidation in the process of breathing causes a mild and genial warmth throughout the frame. All vital activity, according to Liebig, is derived from the mutual action of the oxygen and the food. The fourteen ounces of carbon which are daily burnt into carbonic acid, must be taken in food. A horse burns ninety-seven ounces daily, consuming for this purpose thirteen pounds three ounces of oxygen. The food, therefore, should be in direct ratio with the supply of oxygen. These conditions, joined with a due proportion of sleep, enable a man to perform a daily task equivalent to carrying thirty pounds a distance of 72,000 feet. Any causes which disturb this balance, produce a diminution in the average amount of work performed.

According to the experiments of Dr. Wehrle of Vienna, the oxygen consumed by a candle per minute amounts to 16·6 cubic inches, and the carbonic acid formed to 4·2 cubic inches. When the quantity of oxygen is reduced from twenty-one per cent. to eighteen or sixteen, an ordinary miner's light is extinguished; an Argand lamp will burn until the proportion is reduced to fourteen per cent.

According to Professor Hunt's analysis of air from different parts of the Consolidated Mines in Cornwall, the amounts of oxygen were deficient by 4·75, 4, 3·5, 1·85, 3, and 3·25 per cent. The average of eighteen samples of air, taken from different mines in Cornwall, was—

Oxygen . . .	17·067 per cent. . .	3·933 deficient.
Nitrogen . . .	82·848 per cent. . .	3·848 in excess.
Carbonic acid .	·085 per cent.	

Of six others—

Oxygen	19·34 per cent. . .	1·66 deficient.
Nitrogen	78·75 per cent. . .	0·25 deficient.
Carbonic acid . .	1·90 per cent. . .	1·90 in excess.

The quantities of carbonic acid gas in these cases may have been actually larger, being partly absorbed during the experiments. Traces of sulphuretted hydrogen and sulphurous acid were also found. In the mines of the Hartz the following are the results of accurate analyses of the air by Brockman:—

Deficiency.			Excess.		
No. 1, 1·86	per cent.	oxygen . .	1·8	per cent	carbonic acid.
No. 2, 1·94	"	" . .	1·77	"	"
No. 3, 0·73	"	" . .	1·04	"	"
No. 4, 2·29	"	" . .	2·38	"	"
No. 5, 0·29	"	" . .	0·67	"	"
No. 6, 0·21	"	" . .	0·72	"	"

In all these cases candles could burn, and numbers 3 and 5 were considered samples of tolerable ventilation. It is not uncommon to meet with instances in mines of men working in the dark, from the supply of oxygen being inadequate to keep candles alight; and many instances might be quoted of men sacrificing their lives in these attempts. In the endeavour to keep candles burning, the fibres of the wick are spread out with the thumb-nail, the candles are held horizontally, and several are tied together; after every few blows with the pick or sledge, the miner turns to trim the wick anew. These privations, being unaccompanied with any acute pain to the miner, create for the time only a sensation of lassitude, and difficulty of prolonged exertion; but often is the melancholy remark to be heard from men, young in years but broken in health and incapable of labour—"I worked a month too long in poor air." It is certain that the deficiency of oxygen acts injuriously on the miner's health, long before he is able to appreciate the diminished intensity of the light of his candle with his eye. According to Dr. Bird, a deficiency of two per cent. has been known to be destructive to animal life; and according to Wehrle, a deficiency of eight per cent. will generally cause suffocation; and yet the ordinary practice is to drive a gallery or opening as far from the current of air as the condition of light will permit—a distance varying from 20 to 100 yards, as it is termed, "in advance of the air."

A simple means may be employed for measuring the value of the air for vital purposes in the working-places of mines, by placing a wide-necked bottle, inverted over a candle passed into the cork, first in the pure air, and afterwards in each working-place. The time, in seconds, is noted during which the light will burn; and an arbitrary scale is thus obtained between pure air, and air in which the candle is extinguished, the degrees of which are in proportion to the squares of the time. Similar results may be arrived at by the combustion of phosphorus, or of small tapers, the loss in weight in each being accurately measured.

The anecdote of the fifty-six monkeys dying in the Zoological Gardens in a large domed roof, ventilated only along the floor, illustrates the effect on animal life of a stagnant atmosphere. To such an atmosphere is the miner often unnecessarily condemned. One remark, generally made during the cholera epidemic, pointed to the want of thorough ventilation as the distinguishing mark of those houses visited with its severest attacks. It is also the opinion universally expressed by medical men, mining engineers, and all who have investigated the subject, that the large amount of disease amongst miners is caused by the deficiency of the vital element. Dr. Hanot observes :—"Placed in favourable circumstances for observing two kinds of working-miners in two distinct kinds of coal-mines—the colliers of Dur, where the ventilation is good, and those of Flenu (Belgium) where it is slow and often neglected—I have arrived at the conviction that there existed among them an external physical difference, readily appreciated by the eye, to such a degree that I could point by the finger, when surrounded by workmen, to those who work at one or at the other description of mine."

Underground Gases.—The nitrogen in air is simply incapable of supporting respiration, whereas carbonic acid gas is an active poison. Of this gas 8·5 cubic feet weigh 1 lb. Lights are extinguished when the proportion in the air amounts to from five to eight per cent., and at the latter point suffocation ensues. An excess of 1-500th in the surface atmosphere begins to exercise an injurious effect; and the presence of one per cent. indicates air of very inferior quality. The presence of carbonic acid gas in mines is generally accompanied by an excess of nitrogen, from the oxygen being taken up in the formation of the acid: in estimating the limit within which life is possible, an excess in the air of 4 per cent. of nitrogen + 4 per cent. of carbonic acid gas, may be assumed as producing suffocation.

Carbonic Acid Gas,—called also black-damp, choke-damp, stythe, or sulphur —is found chiefly in the old works, "goafs" or "deads," of mines. It is given off in great abundance by most coal-mines, and by many lead-mines. It is the gas of the Grotto del Cane; and the Pontgibaud lead-mine in the Puy de Dome is remarkable for the difficulty of removing it by ventilation. In this mine, on first starting the pumps, the pressure of the gas with which the air was impregnated was sufficient, on being suddenly liberated by agitation, to raise a column of water several yards in height. Water will absorb an equal volume of the gas. Old workings, shafts, and drifts in mines, especially those which have an outlet only on the upper side, should always be entered with great caution, from the probability of their containing this gas. A light should first be introduced; and if it is extinguished, means should be taken to absorb the gas either by water or lime-water; but, better still, by introducing a current of atmospheric air. If in the bottom of a well or shaft, agitation may be produced sufficient to mix it with the air, by dropping repeatedly bundles of brushwood or straw, attached to a cord. In a recent instance, at the Parkfield Colliery, two men were overcome by carbonic acid gas, which "stood" in an ascending drift. It was only by great exertion, and after fifteen hours' labour, that forty yards of this gas could be passed through and the

bodies recovered, by two men holding one end of a two-inch gutta-percha tube close to their mouths, whilst the air was supplied, at the other end, by means of a blacksmith's bellows.

Carburetted hydrogen—the fire-damp of mines, given off also from stagnant pools and marshes—is composed of two volumes of hydrogen, and one of carbon, condensed into one volume: mixed with more than twice its quantity of air, this gas can be inhaled without producing suffocation; but the introduction of flame, or iron approaching a white heat, will explode the mixture. With less than twice its bulk of air, carburetted hydrogen will not explode, but will burn or extinguish a light introduced into it. When the proportion of this gas forms one-thirtieth of the air in a mine, the miner begins to perceive a pale blue halo encasing the upper portion of the flame of his light: this is caused by the combustion of the gas immediately in contact with the flame. This and the heat generated thereby, cause the flame to flicker upwards to a length of six inches and more, as the proportion of the gas increases to one-fifteenth, when it suddenly explodes. The explosion takes place most rapidly, and with the greatest force when the air contains one-seventh or one-eighth of carburetted hydrogen; but further additions diminish this intensity. The fire-damp of mines contains nitrogen, which affects the above proportions; and the presence of one-seventh either of this gas, or carbonic acid gas, will neutralize the most explosive mixture. It is on the slight and insufficient warning given by this halo or "cap," that the safety of fire-damp mines usually depends. A small increase in the escape of gas from a fissure, or from pressure on the face of the coal, the partial obstruction of an air-way, or the leaving open of a door, will in a few minutes produce a change of one-thirtieth in the composition of the air, and bring it up to the explosive point. To render the halo more appreciable, the miner draws down the wick to diminish the flame, and shades the light of the lower part of the flame with his hand. As increased combustion from the presence of fire-damp has commenced before it thus becomes appreciable to the eye, the writer has fitted a spiral compound metal thermometer to the top of a safety-lamp, which indicates the first accession of temperature, and also offers a wide scale on which the proportions of fire-damp may be quickly, though roughly, estimated underground. The falling of the thermometer will indicate the existence of irrespirable gases.

Carburetted hydrogen, when met with in metalliferous mines, has generally proceeded from the decomposition of vegetable matter. It is occasionally met with in salt mines: and in China, according to the Abbé Imbert, the gas has been obtained by boring to depths extending to 600 yards, to be employed for evaporating the brine. These borings, originally executed for brine springs, having driven off the gas, it is probable that on being carried to a greater depth, the coal measures which frequently underlie the saliferous new red sandstone had been accidentally penetrated.

Fire-damp, the general name for the impure carburetted hydrogen found in coal mines, impregnates even some of the silicious and argillaceous rocks interstratified with the coal; but it is chiefly from the pores or cells of the

coal itself that it exudes. The rapidity and force of the escape produce a "singing" or whistling noise, sometimes as loud as that of letting off steam from a boiler. The pressure has been found by Mr. T. J. Taylor, and others, to exceed four and a half atmospheres; and on the miner cutting unexpectedly into fissures, or faults, the pent-up gas has occasionally discharged itself in enormous quantities into the workings. At the Wallsend colliery a goaf of fifty acres in the Bensham seam, from which the pillars of coal were partially removed, has in the last twenty-two years discharged through a pipe leading to the surface, a bulk of fire-damp equal to seventy times the volume of the coal which originally stood there. This amount of gas, which forms no exception to the general rate of discharge in many collieries, can only have been derived from other seams by filtration through the strata. Whether fire-damp ordinarily exists *in situ* in a highly compressed state, or is given off by the chemical decomposition of the coal under diminished pressure or the access of air, are problems not yet solved; nor is the presence of nitrogen in all fire-damp (derived as it must be from the air) satisfactorily explained. Vessels have been blown up thousands of miles from English ports, by gas continuing to escape from the coal after shipment, and collecting in the hold. A terrific explosion occurred recently in the Cardiff docks, by which a vessel was destroyed and sunk. The force of the concussion was felt at a distance of six miles.

All coals contain by analysis a proportion of hydrogen, varying from $1\frac{1}{4}$ up to 7 per cent.; and from the bituminous down to the anthracite, fire-damp is given off. The most abundant escape of fire-damp is not from the most bituminous coals; and some of the bituminous varieties, generally those which contain most oxygen, discharge carbonic acid gas in lieu of fire-damp.

Fire damp being little more than half the weight of air (24 cubic feet to 1 lb.), collects in the upper part of the galleries and hollows left in the roof. In order to dilute and remove it, it is necessary to introduce an active current of air, which is sometimes directed upwards, by part of a door or some obstruction placed across the lower part of the opening; the outlets for the current of air and gas ought to be left at the higher part of the works.

Bihydro-Carbon, or olefiant gas, is composed of two volumes of hydrogen and two of vapour of carbon condensed into one. This gas has not been satisfactorily proved to exist in any English coal mines; but Bischoff detected it in small quantites in the Gerhard and other mines near Sarrebruck, and in considerable quantities in a lignite mine in Schaumburg. In the latter case, Davy lamps, with a gauze of a finer mesh, were said to be required; but the severe practical test to which the gas in the Gerhard mine was put in the presence of the writer, indicated that no quantity of olefiant gas was present sufficient to render the fire-damp more explosive than usual. No analyses of the gases from mines have hitherto detected the presence of hydrogen, which has been supposed by some persons to render the gas of particular mines more than usually inflammable. A small proportion would suffice to effect this. Common street-gas is composed of 20 per cent. of hydrogen, 10 of olefiant gas, 60 of carburetted hydrogen, and 10 of carbonic oxide; it conse-

quently explodes much more quickly than fire-damp, and at a lower temperature. For this reason many of the experiments which have been made with street-gas on safety-lamps, are deceptive, tending to bring into disrepute lamps which would be perfectly safe underground. Scientific men have thus, with philanthropic objects at heart, unintentionally aided in encouraging prejudices, which continue annually to cause a fearful sacrifice of life.

Sulphuretted Hydrogen, composed of equal volumes of vapour of sulphur and hydrogen, condensed into one volume, exercises an extremely deleterious action on the respiratory functions; it is the most active of the gaseous poisons found in mines, where it is known under the name of "white-damp." It seems to act upon the blood in depriving it of the elements necessary for pròper respiration. 1-15000th part in the air is supposed to act injuriously on the constitution; 1-250th part has been known to kill a horse; 1-1500th a bird. It arises from mineral springs, from the decomposition of minerals, such as iron pyrites and the excrementitious matters which accumulate in the neighbourhood of working roads or places inhabited for many years continuously. Water will take up three times its own bulk of this gas. Its existence may be detected by its blackening white-lead, or paper dipped in sugar of lead. This gas is not unfrequently met with in entering old workings, and in most mines where the means of ventilation are very defective. It explodes at a lower temperature than fire-damp, and the ordinary Davy-lamp is therefore not a sufficient protection. The peculiar smell, resembling that of rotten eggs, indicates its presence; and no attempt should be made to penetrate places where it is perceived, until they have been thoroughly ventilated. Occasionally it commits great ravages on the health of the workmen. At Vanneaux, near Mons, water dropping from the roof of the mine raised lumps on the skin; and its effects were severely felt also at Wasmes, Turlupu, and Jemmapes. The attention of medical practitioners in all mining districts should be directed to it, as, although three per cent. of it may be temporarily breathed without suffocation, a very minute proportion would in time destroy health.

Sulphurous Acid Gas has been detected in the air of the mines in Cornwall and other places; and it is frequently found in the water, which occasionally contains also sulphuric acid. It is one of the products of blasting; but judging from the atmosphere of Swansea, where the copper-works impregnate the air with it, the injurious action on the human frame appears to be but small. Miners are occasionally destroyed by this gas mixing with carbonic oxide, and the other products caused by the firing of timber or coal, or by the spontaneous combustion of old goafs and wastes. The accidents which have occurred show that peculiar caution is required in approaching underground fires. The heaps of small coal left underground in some mines, especially of those seams which contain much oxygen or iron pyrites, are apt to take fire from the heat produced by decomposition with moisture. These wastes must either be closed from the contact of air, as is done at the Moira collieries, by air-tight puddled clay walls; or they must, from the time the coal is first removed, be freelv ventilated in every part. Salts of various metals, such

as zinc, iron, arsenic, &c., may frequently be found crystallizing on the surfaces of rock in mines, being deposited by the vapours given off; but they produce no injurious effect which moderate ventilation will not remove. Mercurial vapours are perhaps the only underground emanations which a well-distributed current of pure air will not render altogether innocuous.

Temperature, Pressure, Moisture, and Dust.—The temperature of the rock increasing according to the depth, affects both the health and labour of the miner, and plays an important part in the ventilation. The extensive experiments of Mr. W. J. Henwood, conducted in the Cornish mines, are summed up in the following table, which exhibits the difference between the temperatures of granite and slate rocks:—

Depth in Fathoms.	Temperature In Slate.	Temperature In Granite.
urface to 50	57°	51·6
50 to 100	61·3	55·8
100 to 150	68	65·5
150 to 200	78	—
200 and upwards	85·6	81·3

The depths causing increments of temperature of one degree are given in the next table, commencing with a normal temperature at the surface of 50°, which corresponds nearly with the temperature, 53°, observed in the caves of the Observatory at Paris, at a depth of ninety-two feet.

Depth.	Granite.	Slate.	Rocks.	Cross Veins.	Lodes.	Tin Lodes.	Lodes yielding both Copper and Tin.	Copper Lodes.	Means.
	Fms.	Fms.	Fms.	Fms.	Fms.	Fms.	Fms.	Fms.	Fms.
Surface to 50 fathoms	9·3	5·0	5·8	8·2	6·0	8·6	6·5	4·6	6·8
50 to 100 fathoms	9·1	7·1	8·1	6·0	8·3	7·3	6·4	8·5	7·6
100 to 150 fathoms	8·3	8·3	6·7	11·0	7·8	8·5	10·5	8·0	8·7
150 to 200 fathoms	—	4·4	3·7	4·9	6·3	—	3·0	4·5	4·5
200 fathoms and beyond	7·5	6·5	9·5	3·9	5·2	5·1	—	6·6	6·4
	8·5	6·2	6·7	6·8	6·7	7·3	6·6	6·4	6·8

The temperature of the water issuing from the Artesian well of Grenelle, 600 yards in depth, is 82°, being an increase of 1° per 59 feet in depth. The result of a series of experiments at the Dukinfield deep pit, in Lancashire, gives 1° per 51 feet as the increment of temperature. The mean of a number of observations on springs issuing in the collieries of the north of England, gives 1° for 48 feet in depth; whilst for several mines in Saxony, Huelgoat

in Brittany, Guanaxuato in Mexico, and a shaft in Siberia, the depths corresponding to this alteration in the temperature of the rock of the mine are respectively 77 feet, 47 feet, 36 feet, and 30 feet, exhibiting considerable variations, which local circumstances will in some measure explain. An isothermal line near the earth's surface, in passing under a mountain, will be deflected from its course without attaining parallellism to the outline of the mountain. Tin lodes are generally some degrees cooler than copper lodes at the same depth; and an unusually high temperature is ordinarily accepted as an indication of large deposits of copper. An example of this has been presented for several years in the north or hot lode of the united mines, where springs enter at temperatures even as high as 116°, at a depth of 220 fathoms. In consequence of the insufficient ventilation (hardly adequate to keep a candle alight), the temperature of the air in which the men worked varied from 100° up to 113°. Three relays of men relieved each other at intervals of five minutes; and on coming out were deluged with water issuing at a temperature of 85° from a four-inch pipe.

The small quantity of air supplied, was heated to 95° before it was sent in through a pipe; whereas ten times the amount of air taken at 75° from another part of the mine might have been readily carried into the level end, so as to keep the temperature of the working places below 85°. Fifteen minutes in this atmosphere is sufficient to produce the sensation of fainting—in one instance it resulted in death; and the cost of driving the levels is multiplied not less than twelve times, by the neglect of the proper means and appliances for ventilation. The miners on returning to the surface from this mine, suffer much from cold and pains in the joints. Humanity recoils at this unnecessary waste of health and life.

The temperature of the air in Cornish mines, at great depths, has been generally found to exceed, by some degrees, the temperature of the lode; this can only be attributable to the heat given off by the men and the lights, and is a proof of the stagnant state of the air. Thus, in Tresavean the rock, at 264 fathoms, exhibited from 83° to 85°; the air 86°. In the Consolidated Mines in Cornwall, at 250 and 287 fathoms, the temperature of the rock was 86° and 93°; the temperature of the air respectively 87° and 94°. At the 294 fathom level the air stood at from 94° to 96°, whilst the rock exhibited 92¼° to 93½°. The air in these two mines has been observed at temperatures as high as 95° and 98° respectively. In the Monkwearmouth Colliery, the deepest coal-mine in England, at 300 fathoms the returning air has been known to reach 89°, although its ordinary range is from 78° to 80°; but it is remarkable amongst the great north of England collieries for the small and inadequate amount of fresh air which can be passed up and down its single shaft.

The return-air of well-ventilated mines, whilst the men are at work, varies ordinarily, at a depth of 400 yards, between 62° and 68°, which represent the temperature of the working-places, either in summer or winter. The loss in the amount of work performed at high temperatures, offers a large premium for attention to underground ventilation; and yet comparatively

few of the managers of mines understand the principles which govern the motions of the atmosphere. Coulomb caused extensive works to be executed by the troops at Martinico, where the thermometer is seldom lower than 77° of Fahrenheit. "I have executed," he says, "works of the same kind by the troops in France, and I can affirm that under the fourteenth degree of latitude, where men are almost always covered with perspiration, they are not capable of doing half the work they could perform in our climate."

The following table illustrates the changes of temperature exhibited by the air in passing through the Marquis Pit:—

	Fah.	Fah.	Fah.	Fah.	Fah.
At the surface	79°	62°	57°	50°	55°
At 120 yards deep	78	60	55	51	56
At 246 yards deep	68	59	55	53	58
Horse-road between shaft and work	—	60	60	57	60
The workings	73	69	67	68	69
In the gobbing or floor	—	67	68	68	65
Salt water in the air-way	—	63	61	61	60
In the egress air-way	—	69	68	67	68
Men and lads in the pit	—	81	81	80	80
Horses	—	21	21	21	22
Candles lighted	—	96	100	100	100

The workings are from 800 to 1200 yards distant from the bottom of the shaft. In districts where ventilation is not understood, it is commonly asserted by miners and others, that the deeper the mine the more difficult the ventilation; when, as will presently be shown, the contrary should be the case. Many parts of the deep metalliferous mines are altogether abandoned in consequence of the poor air and high temperature. That this is neither due to the heat communicated by the rock, however deep the shaft, nor to the thousands of yards which it may be indispensable for the air to travel before it reaches the surface, may be illustrated by an experiment at the Seaton Colliery. The shaft was 260 fathoms in depth and 14 feet in diameter, divided in the middle by an air-tight partition ("brattice"). The mine had not been worked for two years. The length of the air-course underground was 1012 yards, and the area of the passage 24 square feet. The surface of the air-course exposed to the air was 60,720 superficial feet, at a temperature of 80°. The air at the top of the shaft was at 44°, which rose to 49½° as it reached the bottom of the shaft. 7000 cubic feet of air per minute passed through the air-course; and although exposed in its passage for ten minutes to surfaces of rock 30° higher in temperature, it only gained 3° in travelling upwards of half a mile from shaft to shaft. The air gained 5½° in descending, according to the usual rule of 1° increase of temperature for every 300 feet of descent, due to the increased pressure of the air, which it again lost on returning to the surface, where it exhibited a temperature of 46°.

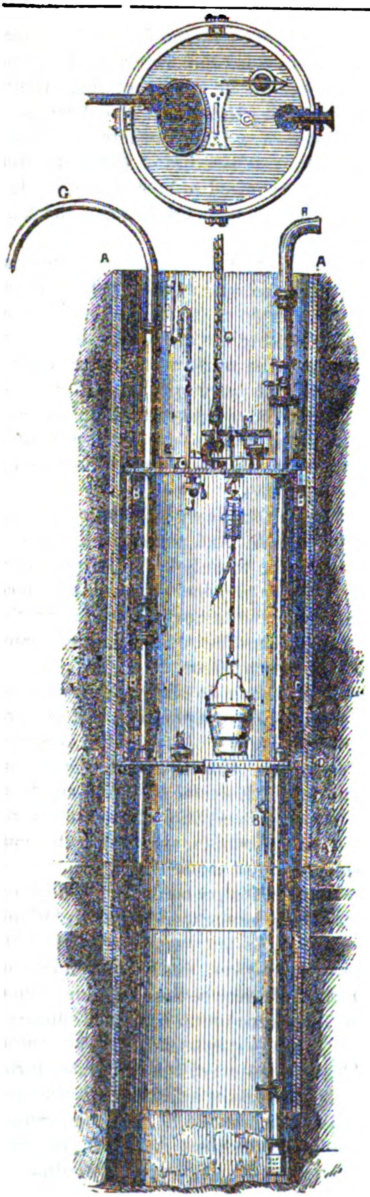
According to the experiments of Despretz, a miner, on the average gives

off sufficient heat to raise 34,000 cubic feet of air at 52°, one degree in temperature per hour. His candle will communicate this temperature in the same time to 26,000 cubic feet. The heating power of 20 men and their lights would raise, therefore, 2000 cubic feet of air per minute, twelve degrees of Fahrenheit, viz. 52° to 64°, the temperature of a well-ventilated working-place. Without taking into consideration the temperature of the rocks, 100 cubic feet of air per minute would be then required to be supplied by the ventilating current, and 400 cubic feet for a horse, in order to keep the temperature of working-places within proper limits.

In the ends where miners work, there is often a difference of several degrees between the warmth of the air at their feet and at their heads, where the function of respiration is going on—an example of the imperfect diffusion of gases which takes place, but a means of assisting the circulation of the air, provided the main current were brought near the workman. In hot mines, the men are more subject to take cold, either from passing to and fro into the cooler incoming air, or in walking home. The boys between ten and fifteen, who bring out the minerals from the working places, are in a perpetual change of temperature, often of 20° every few minutes; and consequently suffer in a high degree from pulmonary complaints.

Although man can bear for a short time, without serious results ensuing, temperatures varying from — 50° up to + 300° Fah., and pressures of three to four atmospheres in a diving-bell, or its reduction to only half an atmosphere on the summit of Mont Blanc, we perceive, by the physical differences of races inhabiting the temperate and torrid zones, mountainous districts, or flat countries nearly level with the sea, how large an effect on the human frame comparatively small atmospheric differences may produce.

The pressure of the air in mines has been shown to slightly augment the temperature, the latent heat becoming sensible by compression. It also exercises an almost inappreciable effect in supplying more readily the requisite quantity of oxygen to the lungs. Persons have sometimes imagined that they experienced an addition of strength from this cause, whilst in the fresh air at the bottom of the deepest mines; but as this additional pressure never exceeds one-tenth of an atmosphere, the effect of which, as regards the compression of the oxygen, would be the same as that caused by a lowering of the temperature of the air at the surface by 50°, it is probable that it does not materially benefit the miner. Asthmatic colliers prefer working in the Monkwearmouth deep pit, to which I have referred, feeling temporarily relieved; but this may arise from the high temperature—liked, indeed, by most old miners, however injurious to health and strength may be the conditions which attend it. The pressure of air produced by a force-pump has been employed for sinking several shafts on the Continent through quicksands, and the water-bearing marls of the chalk formation. The application of this apparatus is due to M. Triger, who applied it in the year 1839 in sinking a shaft sixty-three feet deep through quicksand near Challonnes, on the banks of the Loire, which flowed freely into any excavation attempted to be made to reach the coal strata beneath. The following figures represent the shaft and apparatus.



The wrought-iron tube A A, four feet six inches in diameter, was first driven in by a monkey. The wrought-iron case B B, in principle resembling a diving-bell, was lowered by the rope C, and fixed by air-tight wedging at D D. The case was provided at E and F with man-doors opening downwards, by which the workmen entered the case or passed through it to the bottom of the shaft. The pipe G conveyed the air into the bottom of the shaft; whilst the water which could not be forced back by the pressure, escaped by the pipe H to the surface. Each of these pipes was furnished with cocks. J and K are the cocks for equalising the pressure of the air. The pressure-gauge and safety-valve are lettered L and M. After the workmen had passed through the upper man-door, the air in the case and underneath it was condensed by the air-pump to a pressure not exceeding three and a half atmospheres. In ascending, or in removing the material excavated from the case, the lower man-door was first closed; and by the cock J in twenty minutes the pressure was relieved, and the upper man-door was opened. As the shaft was sunk, lengths of wrought-iron tubeing were added; and after the excavation had penetrated six yards into the solid rock, strong wooden curbs were joined into the bottom of the tubeing.

The effects produced on the miners working in this atmosphere were very remarkable. In consequence of the pressure of air, speaking required an effort, and the voice assumed a nasal tone, whilst some of the higher notes of the voice were lost. It was impossible to whistle; and one miner somewhat deaf could hear better than his companions.

The pulse was not quickened; respiration was slower, and more free; the actual labour at the bottom or in ascending the ladders was less than in ordinary air; but all the workmen, with one exception, were attacked, after quitting the apparatus, with severe pains in the joints, which required the use of hot-baths and rubbing with spirits of wine or ether to remove. The combustion of the candles proceeded so rapidly, and created so dense a smoke, that hempen had to be substituted for cotton wicks. On opening the cock *j*, to allow the air in the case to escape, it was filled by a dense and intensely cold fog, caused by the absorption of heat by the air in expanding. The effects were most injurious when the men had made a full meal, or had indulged in any excess before coming to work, or when the pressure of the air was thrown on or off too suddenly. The foreman and one of the new hands died from its effects; and a serious accident occurred in sinking the Douchy shaft, near Valenciennes, by the bursting of the case, which caused the death of six men. This, and the sufferings of the workmen when exposed to a pressure as high as $3\frac{4}{10}$ths atmospheres for four hours successively, have prevented this system from being resorted to except in extreme cases.

Moisture.—The air in mines is charged with moisture: the hazy atmosphere underground, and the appearance of the air issuing from the mine even on a warm day, attest this. On a hot summer day the phenomenon may sometimes be observed of moisture condensed on the inside of the shaft, and on the surface of the mine, in consequence of the air cooling in its descent; the air being at the same time brought nearly to the point of saturation with aqueous vapour. Numerous observations with the hygrometer, both in Belgium and in England, exhibit the fact that the current of air, however dry it may have entered, after it has passed through indifferently ventilated working places, is nearly at the point of saturation. The more vitiated the air, the greater the amount of moisture, as the following considerations will explain. A working miner exhales and throws off in perspiration from 6 to 8 lbs. of water per day. Horses perspire more freely than other animals. To be added to these sources of moisture is that acquired by the air in descending or traversing wet shafts and air-ways, or derived from the combustion of lights and gunpowder. Dr. Hanot remarks, that this condition of the atmosphere is one of the most hurtful to the animal economy. The various functions languish; the tissues become relaxed; the fluids of the human body tend to escape, in consequence of the accumulation of caloric; and soon the perspiration which the air, already charged with humidity, is unable to carry off, streams down the bodies of those working under these influences. The impurity of the air, in its relation to the health of the workmen in the mines where they work, can be estimated from the number of degrees of the thermometer, compared with those of the hygrometer; and from the degree of height at which these instruments stand, a conclusion can be drawn as to the degree of corruption of the atmosphere of the mine. By a judicious use of the thermometer alone, and observing its gradual rise in walking from the shafts by which the air enters up to the working places, the localities of defective ventilation may be detected as well as the leakages of impure air from old workings, which

might otherwise escape observation. It is well known that high temperatures accompanied with moisture, especially rapid changes of them, are extremely productive of disease amongst artizans. Moisture is the very common vehicle in which other agents of disease are dissolved and brought into action with greater intensity. These facts have an important bearing when we consider the amount of malaria now pervading the air of mines. It is sufficiently evident, that to obtain the greatest amount of work from a man in a given time, it is necessary to supply air not only cool, but tolerably dry.

Dust.—The dust which floats in the air, of some collieries more particularly, is often referred to as productive of permanent injury; but more accurate observations have determined that melanosis and other affections which may result from it, are also produced in other mines, and are attributable rather to the carbon arising from the imperfect combustion of tallow or oil of bad quality, which prevents the free access of oxygen to act on the blood. Carbon, after a time, actually appears to be formed in the lungs, the fine soot being found to deposit in the creases of the tissues of the membrane of the lungs. Few miners are exempt from this affection—it claims a prescriptive right of residence; whereas coal-dust is thrown off by coughing and expectoration. The disease seldom, if ever, occurs amongst men working in coal-dust on the surface. The managers of some mines are deservedly particular in obtaining the best quality of candles and oil for lighting, in order to avoid the loss and injury arising from imperfect combustion—an evil which is aggravated and rendered doubly pernicious by poor air.

On the other hand, cases have been known where a cloud of dust has alone produced suffocation. In one instance, the person unconsciously inhaled the dust brought by a rapid current of air on the upsetting of a tram of fine coal: in another, two men were found dead in a ladder-shaft, with their candles still alight, but covered with dust thrown up by an explosion of fire-damp. The effect could not have been due to the irrespirable gases which result from such an explosion, otherwise the lights would have been also extinguished. It is probably owing to the hot, fiery dust, vomited forth in a black cloud even to the surface, which accompanies these explosions, that the number of deaths from suffocation, amounting often to seventy per cent. of the number of the killed, is chiefly to be attributed. Colliers have been enabled to pass many hundred yards past the bodies of their dead and dying companions, by simply covering the organs of respiration with a thickness of cloth; if first wetted and tied over the face, so much the better. In July last, a Welsh collier, in company with four others, descended a shaft filled with a cloud of this dust, in the heroic, though rash endeavour to succour ten of his fellow workmen who had been overcome by an explosion of fire-damp. The leader of this forlorn-hope fell a victim to his humanity. In commencing some of the workings in the interior of the Standedge railway tunnel, nearly one-third of the miners were prostrated by a pulmonary complaint affecting both their strength and their throats. By stopping the smoke from the fires of the canal boats, and by better ventilation, the evil was removed.

Sanitary Effects and Mortality.—Deprived as a miner is, at least

in the winter months, of the beneficial rays of sunlight for six days out of seven, it is difficult altogether to reject the idea that he permanently suffers from this cause, although it is difficult to estimate its results. In hot climates the shady side of a street, under some circumstances, is more unhealthy than the other, and individuals labouring under asthmatic complaints are very sensitive to the benefit of light; but much, no doubt, is also due to the heating and rarifying rays. On this has been founded, and with some justice, an argument, for working two shifts or turns of men underground—the first from 4 A.M. till 12, and the second from 12 A.M. till 8 P.M. The mining engineers of Belgium are, however, mostly of opinion that the night-work in their mines is preferable to the day-work, and does not so seriously affect the workmen; one of the arguments used being, that from the surface atmosphere being cooler, the ventilation is better by night than by day.

It is unnecessary to enter at length into the effect of the variety of exhalations and miasmata proceeding from the putrid fermentations of animal and vegetable matters underground, as they are well known even upon the surface. In these confined channels, where the accumulations exist at every step, the warm, moist atmosphere gives them every facility to produce their direst effects. When it is considered, however, that each workman produces 46 lbs. of excrement per annum, and that this, neglecting all sanitary laws, is allowed to remain in and about the working places, and in the dead ends which the air current does not enter, it is evident that a fertile source of miasmata exists, whatever care may be used in covering the deposit; while underground stables and accumulated dungheaps are often most injudiciously placed close to the incoming air, in which also the horses stand, or are constantly working to and fro; and almost a forest of timber, used for supporting the roof and sides, is continually undergoing dry rot, which under bad ventilation consumes it in two years. It will be seen that the old workings, technically called goafs or deads, are also vast laboratories for the decomposition of minerals, timber, and animal remains. It is a common thing, indeed, to find openings left from them into the incoming vital current of air for the free percolation of the noxious products in sufficient quantity to extinguish a candle at the point where they enter.

In places where such accumulations are unavoidable, if the whole space is not completely closed by the pressure of the ground, a slight current of air carried through or above them into some surface outlet, or into the outgoing air, will remove or moderate the evil effects. Stables should be kept clean, and frequently whitewashed; but horses in mines generally thrive well, as they work in the purest of the air, before it has reached the men.

The other nuisance alluded to was at the Standedge tunnel, remedied by supplying iron trams with iron lids on hinges to each range of work, and placing them in the outgoing air. They were brought out every few days to be emptied, and in two years paid their cost. In estimating the effect in producing disease of all the various causes which we have described, it must be recollected that the adult workmen are seldom exposed to their action, where the concentration is greatest, for more than eight hours con-

secutively. Many of them pass occasionally in and out of the working place at meals and other times; and many of the lads are as much in the air current (whatever that may be) as in the unventilated ends.

Mr. Ratcliffe's tables give the duration of life of miners at not much under the average of England and Wales; but appended to them is this remark:— "This class of lives shows a very large amount of average sickness at every period, and increased sickness with advance of years. From the very nature of the employment, this was to have been anticipated, but not to such an extent as appears from these results. At age 20, miners experience an average sickness of 46 per cent. more than the general class; at age 30 they show 70 per cent.; at 40 years, 78 per cent.; at 50 years, 76 per cent; and at 60 years, 53 per cent. more average sickness than the general class of lives. The aggregate amount of sickness experienced by miners for the period of life 20—60 is 95 weeks, showing an excess of about 67 per cent. more than the general results. Had these lives which form 4·93 per cent. of the general class been first extracted therefrom (which should have been done), it would have shown a less amount of average sickness experienced by the general class, and consequently would have proved that miners are subject to more average sickness per annum in excess of the general class than appears to exist."

But these tables do not include lives under 18 years, before which time it will be shown that not only disease, but an excessive mortality occurs. The Registrar-General has supplied some valuable statistics respecting the mining population, numbering 10,690, in the district of Merthyr Tydfil, forming part of a population of 41,425 males, and 35,379 females. The town and rural population are about equally divided:—

Age.	Annual rate of mortality per cent. of males in England, 1838 to 1850.	Annual rate of mortality per cent. of colliers and miners in Merthyr Tydfil, 1849 to 1853.
10	·515	1·632
15	·825	2·055
25	1·001	1·999
35	1·283	2·296
45	1·843	3·308
55	3·203	5·450
65	6·746	12·639
75	14·745	21·818
85 and upwards	38·424	53·333

This table affords a comparison in the rates of mortality at different ages between males in England generally, and the miners in this district; and shows that the noxious influences at work on these miners are sufficient to treble the destruction of life between the ages of ten and twenty-five. The ratio is, in fact, still higher at the commencement, showing how immediately destructive are such causes to the constitution at an early age; and how the hardier constitutions who survive the first trial to health, become more acclimatized. It is also found that between the ages of fifteen and twenty-five one-third of

the deaths occur from diseases of the respiratory organs, and that more than one-third of the miners meet with violent deaths.

The next table exhibits the after-lifetime, or prospect of life, of males in England, and of colliers and miners in the Merthyr Tydfil district, at different ages.

Age.	After-lifetime. Males in England. Years.	After-lifetime. Colliers & Miners in Merthyr Tydfil. Years.
15	43·62	31·76
25	36·60	27·86
35	29·82	22·92
45	23·13	17·54
55	16·66	12·44
65	10·90	7·77
75	6·57	5·61
85	3·74	4·53
95	2·11	4·30

The table may be read thus:—Men who attain the age of 25 will live, on an average, 27·86 years in Merthyr Tydfil, if their occupation is that of a collier or miner. The mean after-lifetime of a miner or collier aged 25 is, therefore, 27·86 years in Merthyr Tydfil; while the mean after-lifetime of a man aged 25, is 36·60 in England generally. The vital statistics of the population generally of the parish of Merthyr Tydfil, as compiled by Dr. Kay, exhibit a very high rate of mortality. It is under the influence of the wealthy proprietors of its noted iron-works and mines; and though its situation is naturally healthy, being at the head of a rural valley, it is remarkable as approaching—perhaps more than any other town in England, and as nearly as habitations on the surface can do—to the unventilated and noxious condition of the mines of this country. A conclusion might be drawn, that the pernicious influences to which the miner is subjected in his subterranean labours are so great, that he passes almost unscathed by the malaria on the surface.

In Cornwall, it has been ascertained that 61 per cent. of the miners die from diseases of the chest, and only 31 per cent. of the rest of the population. Pulmonary emphysema, asthmatic affections, rheumatism of the joints, and pneumonia, are the commonest diseases amongst miners, and proceed from the conditions in which they work. When young boys are sent into the mines, their growth is generally checked, and the vital processes seem, for a time, to go back, until they accumulate strength. The chest frequently enlarges unnaturally to allow of breathing in positions and circumstances which nature has evidently not provided for: certain parts of the frame are developed at the expense of others. Some mines are noted for particular diseases; one, belonging to seams about three-quarters of a yard in thickness, is called the three-quarter cough. A peculiar disease, anemia, showed itself extensively at one time in Belgium; the skin became the colour of wax, the veins contracted, and the circulation almost ceased. It was, in fact, one of the extreme

results of that enfeebled state of the vital functions which is the normal condition of miners when subjected to insufficient ventilation.

In the Report of the Children's Employment Commission on Mines, 1842, it is remarked—"The iron-stone pits are in general less perfectly ventilated and drained than the coal-mines, and are therefore still more unhealthy, producing the same physical deterioration, and the same diseases, but in a more intense degree. The ultimate effect of the disadvantageous circumstances under which the miner in tin, copper, lead, and zinc mines is obliged to pursue his laborious occupation, is the production of certain diseases (seated chiefly in the organs of respiration), by which he is rendered incapable of following his work, and by which his existence is terminated at an earlier period than is common in other branches of industry, not excepting even that of the collier. The primary, and ever-acting agent, which principally produces this effect, is the noxious air of the places in which the work is carried on." A surgeon writes—"In reality, what is this number of violent deaths (and I appeal to my fellow-practitioners at collieries) compared with those thousands of persons who advance day by day bowed down to a premature death, arising from their occupation, and which brings on an old age, overwhelmed with infirmity, at a period when other men still enjoy the plenitude of their strength?"

In the following table will be found the relative numbers of miners and agricultural labourers employed at each age in Great Britain:—

Occupation.	Total in Great Britain in 1851 by Census.	5 to 10	10 to 15	15 to 20	20 to 25	25 to 30	30 to 35	35 to 40	40 to 45	45 to 50	50 to 55	55 to 60	60 to 65	65 to 70	70 to 75	75 to 80	80 and upwards	Total.	Average age of living.	Age of commencing work.	Age of leaving off work.	Number of years of labour.
Coal-miners . .	216366	5	124	171	169	130	100	94	62	48	36	26	18	10	6	2	1	1000	26·1	11·2	39·7	28·5
Iron miners . .	27098	5	97	147	194	160	122	92	64	45	31	19	13	7	3	1	—	1000	26·8	13·4	38·8	25·4
Lead miners . .	21617	3	79	147	167	143	112	94	75	60	46	31	23	12	4	3	1	1000	28·9	12·9	42·5	29·6
Copper miners .	18468	10	116	183	156	127	100	82	65	57	43	27	17	10	4	2	1	1000	26·4	11·6	38·9	27·3
Tin miners . .	12912	12	143	178	150	116	89	79	63	56	41	30	20	11	7	4	1	1000	25·7	10·6	38·2	27·6
Agricul. labourers	1006728	6	75	115	113	108	98	88	80	72	67	51	47	32	24	14	10	1000	34·2	11·3	53·6	42·3

The latter class is selected for comparison, inasmuch as mining is usually carried on in or near agricultural districts, and the wasting ranks of the miners are supplied from them; and it will be shown that the occupation of the miner is not necessarily much more unhealthy. The last four columns present, as well as the materials for such a calculation would allow, the average ages of the whole of the persons following these occupations in 1851, the ages of commencing and leaving off work, and the average number of years of work done by each class. Hence it appears that the average age of miners living, varies from 25·7 years in the case of tin miners, to 28·9 amongst lead miners, being a difference of about three years; but this is accounted for by the tin miners commencing work at 10½ years of age, the lead miners not till about 13 years. These are the extremes of age within which, on an average, each of the five classes of miners begin to work.

The result bears out the opinion as to iron mines being the unhealthiest of all, for, notwithstanding that the men do not commence work until 13 or 14 years of age, their span of labour only reaches 25·4 years, which is 2¼ years below the average time in which a miner wears out. The miners last but 27·7 years, whilst 42·3 years are got out of the agricultural labourer. In other words, the lives of the miners, in addition to excessive sickness and diminished strength, are shortened by an amount equivalent to more than half their working life.

These tables are, to a great degree, confirmed by limited observations in particular mining districts. Mr. Blee, in 1847, comparing the agricultural and mining population in Cornwall, gives 52½ as the average age of the former, 42 of the latter; in neither case including any below 10 years of age. Again, of the total number of males dying in 10 years, there died per cent. between the following ages—

District	Gross Male Population.	— to 10	10 to 20	20 to 30	30 to 40	40 to 50	50 to 60	60 to 70	70 to 80	80 to 90
Not Mining	10322	42·4	4·6	6·9	6·6	6	7·2	9	10·9	6
Mining . .	10869	42·8	7	8·4	7·9	9·4	10·6	7	4·7	2·7

Economy of Pure and Cool Air.—It has already been shown that one-third of the value of the miner was cut off by the hand of death; but the causes which have brought him to the tomb must have necessarily diminished the amount of work he is able to perform, even in his best days; and during one-fifteenth of his working life, he depends on the sick-club or the parish for support. He has good grounds, therefore, for demanding a high rate of wages, and he is especially in need of the assistance of benefit societies in his period of trial. "As an evidence of the good economy of spending money to lessen these terrible effects of the miners' occupation," Mr. Blee states that "from a return made by the relieving officer of Gwennap to the Redruth Board of Guardians, he has ascertained that of 240 families receiving parochial relief in Gwennap, in one quarter of a year, upwards of 200 were miners' families; and that of the fathers of those families 15 had been killed in the mines; 40 had been blinded, maimed, or so injured otherwise by mine accidents, as to be unable any longer to earn their own livelihood—many of the injuries, at different distances of time, having terminated fatally; while 65 have died, and 15 others, who had among them 80 children, were dying more or less slowly of miners' consumption."

In tracing out the remedies to be applied to render the cell of the miner a fit place for human beings to pass a large portion of their lives, it is necessary to point out that it requires no other remedy, except in a higher degree, than we are now adopting on the surface. The same rules of ventilation, the same habits of cleanliness, will suffice. The mines have reached their present condition, just in the same manner as a portion of any town inhabited by the

poor, unvisited by the owners of the property or intelligent and professional men, would infallibly become the stronghold of disease. Miners themselves, until the candles burn dimly, are so little conscious of the effects of imperfect ventilation, that they commonly object to improvement; and yet they have admitted, after a sufficient trial of a better system, that they could do one-fourth more work in properly ventilated mines.

There are many mines, or parts of mines, which can hardly be worked in summer, because candles will not burn in the working-places. The ventilation entirely stagnates in the act of reversing. The powder-smoke hangs in the face so as to cause a delay of half an hour after each shot is fired.

Such are a few of the conditions which, occurring frequently amongst a large number of men in mines where no artificial means of ventilation are employed, produce losses on a large scale. They are customary, however, and consequently seldom appreciated by the proprietors.

From the evidence given by Mr. Woodhouse of Overseal, mining overseer of the Moira Collieries, who has had great experience in the ventilation of coal-mines, it appears that a large saving is invariably realised in practice from the adoption of improved modes of ventilation; because the constant introduction of fresh currents of atmospheric air into the pits, tends, in a remarkable degree, to protect the woodwork of the mine, and to keep the road-ways dry and in good order.

After speaking of the drawbacks from the profits of collieries arising from an imperfect system of ventilation,—imperfect as regards the whole quantity of air passed through the workings, but still more imperfect as to its distribution, he says:—"The improved system adopted in the collieries on the Tyne and the Wear, of dividing the workings into districts, and so obtaining a current of fresh air in every division, may, in many cases, be adopted at a trifling expense in other countries; and although the extent of the workings, in general, bears no proportion to those in the collieries in the north, the principle remains the same, and the result would be favourable in a corresponding degree. It may be urged that the immense quantity of gas given out of the coal in the north, has called for the improved system: this is probably the fact; but there are many advantages to be derived from good ventilation beyond the mere prevention of explosion. In pits with a rapid circulation, the men respire more freely; the road-ways are kept dry, and repaired at less expense; and the timber lasts longer *by years*: and therefore it is a matter of strict economy to ensure a good ventilation." There are few mining engineers who will not subscribe to the correctness of the Report of 1842: "That a mine, when properly ventilated and drained, and when both the main and the side passages are of tolerable height, is not only not unhealthy, but the temperature being moderate and very uniform, it is considered, as a place of work, more salubrious and even agreeable than those in which many kinds of labour are carried on above ground." To effect this, the chief regulations to be unremittingly carried out are, that no man shall be suffered to work in a stagnant atmosphere; and that the working places as now existing—the reservoirs of all the deleterious gases brought

along by the air-current—shall have a current sent through them into every part in sufficient quantity to dilute all the deleterious gases, and deprive them of their power; or, in the words of the resolution passed by a meeting of deputies from the coal-mining interests of the kingdom in May 1854—"That adequate artificial means of ventilation be provided at all collieries; and that there shall be at all times a sufficient current of pure air through the workings, to dilute and render innocuous all noxious and deleterious gases."

Alterations in Density the Cause of Motion in Gases.—Air or gas confined in a vessel presses equally on each square inch of its surface, and also on the surface of any body enclosed within the vessel. Mariotte demonstrated that under one-half of this pressure, the air would occupy twice the space; under double the pressure, it would contract into one-half the volume. In other words, that the pressure is in inverse proportion to the density of the air and the space it occupies. The pressure of the air in the vessel can be readily ascertained by fitting a bent glass tube into the side, and measuring the height of the liquid mercury, oil, or water, which is supported by the pressure. Such an instrument (represented at A, Fig. 3) is the ordinary barometer, in which thirty inches of mercury will support a pressure equivalent to that of the whole atmospheric column, or to 26,250 feet of homogeneous atmosphere, at a temperature of 32°. The weight of a column of mercury one foot square and thirty inches high, weighs at 32°, 2122 lbs. The pressure of dry air will, therefore, be equal to nearly 19 cwt. on each square foot of surface. If the tube is open at the top, like the ordinary water-gauge used in mines, the height of a column of water in the tube B measures the variations between the pressure in the vessel and that of the air outside. According to the most accurate experiments, 100 cubic inches of air at 60°, and 30 inches of mercury, weigh 31·0117 grains; 13·06 cubic feet are therefore contained in 1 lb. The heights of columns of equal weight and area are—of quicksilver, 0·88 inches; of water, 1 foot; of air, 815 feet.

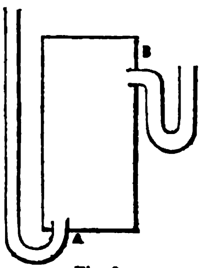


Fig. 3.

Gay Lussac found that air expanded uniformly by equal additions of heat; and the later experiments of Magnus and Regnault have determined that this expansion for each degree of Fahrenheit is 1-459th part of the volume of the air at zero; consequently the increase in bulk at any higher temperature is

$$\frac{\text{vol.} \times \text{temp.}}{459}$$

And generally at any other temperatures the

$$\text{vol. at temp. (No. 2)} = \text{vol. at temp. (No. 1)}\ \frac{459 + t\,(2)}{459 + t\,(1)}$$

The specific gravity of any gas of a standard measure and temperature being known, we can, by the two laws just given, determine its weight at

any other pressure and temperature. When several gases of different kinds are contained in the same vessel, they tend to stratify themselves in the order of their densities; but at the same time to diffuse one into the other, so as to become perfectly mixed. Thus, if a jar of light carburetted hydrogen be inverted over a jar of carbonic acid gas, the heavy gas will ascend and the light descend, until the jars are filled by a uniform combination of the two gases. If equal bulks of three different gases at the same temperature be condensed into one volume, the resulting pressure will be the sum, viz. three times the original pressure. They conform to the law of Mariotte in the mutual relations of volume, density, and pressure, and to the law of Gay Lussac in the same manner as air. It is frequently necessary to consider the effect of aqueous vapour when mixed with air. When the air is not saturated with vapour, the elasticity and density of the latter, and its weight in a cubic foot of air, are determined by the hygrometer and the tables accompanying the instrument. The modes of calculation may be found in the CIRCLE OF THE SCIENCES, article "Meteorology," page 576.

The alterations in the pressure and temperature of the air, or the admixture of aqueous vapour above described, produce changes in the density of the air, which result in motion. If in the last figure the water-gauge B were removed, so as to leave an opening in the thin plate which forms the side of the vessel, the gas would immediately press through this opening, and escape with a velocity which would depend on the excess of pressure of the gas in the interior over that exterior to the vessel, as well as on the specific gravity of the gas. If the exterior pressure, on the contrary, exceeded the interior, the air or gas would flow in, obeying the same conditions. The amount passing in a given time depends on the form of the orifice (Fig. 4). If the stream passes through a thin plate, it suffers a convergence, or contraction, of its parts (called the vena contracta), which reduces the amount to $\frac{64}{100}$; and if through a short cylindrical or conical tube, to $\frac{82}{100}$ and $\frac{86}{100}$ respectively, of the amount which would be due to the velocity if it took place over the whole area of the external opening.

If the stream of air passes through a long horizontal tube of uniform area (A, Fig. 5), the amount discharged from the extremity will be diminished by the resistance offered by the sides of the tube, which also equally diminishes its velocity. This resistance will be in proportion to the interior surface of the tube exposed to the friction of the air in motion; that is, to the length and circumference, as well as to the density of the air and the velocity of its motion. If the air passes, as in Fig. 6, from the long horizontal tube A into another B, the quantity discharged will be diminished by the increased resistances offered by the higher velocity in the tube B, and by a small loss from the vena contracta in passing from a large to a smaller tube. If the air in traversing the tube is made to pass through an aperture in a diaphragm C (Fig.

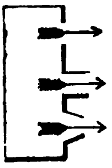


Fig. 4.

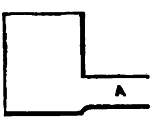


Fig. 5.

7), the velocity, both before and after passing the opening, will be equal; but there will have been a loss in consequence of the resistance encountered in passing the thin plate.

If the tube is inclined downwards or upwards, as in the

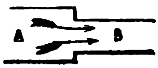


Fig. 6.

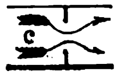


Fig. 7.

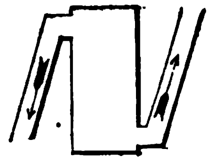


Fig. 8.

diagram (Fig. 8), the velocity of the current will be increased or diminished, according as the force of gravity acts in the direction of the current or contrary to it. In all cases, the resistances can only be overcome and motion produced by an increase or excess in the density of the air; consequently the difference in the density of the air before and after passing the resistances, will represent the expenditure necessary to evercome them.

Natural Ventilation.—If A B in Fig. 1, Plate III., represents a gallery or level driven into the side of a hill, and B C a shaft at its extremity, then the temperature being uniform throughout, the pressure of the atmospheric column will be equal on each square foot of the bases A and B; the densities of the columns A D and B C will be the same, and no motion will be produced. If the density of either the column A D or B C be altered, the equilibrium of pressure will be destroyed, and motion will ensue; the heavier column must descend to force up the lighter one with a velocity proportioned to the difference in the weights of the two columns, or of the atmospheric pressure on their bases. The two columns may be compared to two liquids of different densities in the branches of a siphon, or to unequal weights connected by a cord passing over a pulley. If the external air is heavier, the air in the shaft would be forced upwards; if that in the shaft is heavier, the air will be discharged from the mouth of the level. It follows, that if we suppose the temperature of the mine to be constant, and to impart its heat to the air as it passes along the level A B, the air will enter the level mouth whenever the atmosphere is colder than the mine, and descend the shaft whenever it becomes warmer than the mine. C D may be supposed to be the surface of the ground, and D A, C B two shafts of equal depth. In such a case, no motion would ensue from the changes in the temperature of the external atmosphere; but if by any means we can alter the density of one of these columns, motion will be produced, and continued at a velocity controlled by the principles previously stated. By exhausting or compressing the air in one of the columns by means of air-pumps, or by heating, the requisite difference in density can be effected. This is termed artificial ventilation, as distinguished from natural ventilation, which is generally taken to include the effect of rarefaction from the temperature of the rock, and from the lights and persons who may be employed in the mine, as well as from the gaseous exhalations. When air has been set in motion in shafts of equal depth, the gradual changes of temperature which it undergoes by the absorption or loss of heat, produce a difference in the tem-

perature of the two shafts, which continue the motion until atmospheric changes occur sufficient to neutralise it.

An example of natural ventilation has been already given at the Seaton Colliery, where no men are at work. The following experiment at the Tyne Main Colliery was made by Mr. N. Wood, whilst the mine was at work:—Depth of shaft, 672 feet. Temperatures: at surface, 43°; bottom of downcast shaft, 45°; air returning from workings, 63°; in upcast shaft, 390 feet from surface, 62°. Quantity of air in cubic feet per minute, 37,000. From this it appears that a difference of 18° existed in the temperature of the air in the two shafts, and that the mines and workings gave off heat equivalent to raising 666,000 cubic feet of air per minute 1° in temperature. When the atmospheric temperature increases to about 62°, that is, to the tempera tureof the air ascending the upcast, the effect of the natural ventilation ceases, the air of the mine becomes wholly stagnant, and requires the application of artificial means to set it again in motion, as in Fig. 2, Plate III., where, if the shafts A B and C D in the figures are of unequal depth, but united by a horizontal gallery B D, the air wlll ascend the deeper shaft in winter, and descend it in summer. This may be readily understood by comparing the equilibrium of two columns of air of equal height, A B and E D. In winter E C and C D are both colder, and consequently more dense, than the parts at the same levels A F and F B, although C D receives a slight increase of temperature from the rock. In summer, on the contrary, the air contained in F B and C D is nearly of the same temperature; whilst the part A F has been cooled by the rock so as to become denser and heavier than F C. The air has frequently to ascend and again to descend in traversing the air-ways in the mine. The ascent in winter will be materially lessened if, after entering the shaft C D (Fig. 3, Plate III.), its temperature continues to be raised whilst traversing the interior shafts or sloping drifts, H G and E F; for then the column, being lighter than G H, counteracts the motion. In summer, as the current of air passes in the contrary direction, the cooler and denser air in G H will aid the current; and this effect will be greatest when the air, in passing from E to G, has been cooled to the lowest degree attainable in the mine.

When the underground shafts or sloping drifts communicate with levels at different heights, as represented in Fig. 4, Plate III., the effect on the ventilation in winter will be favourable, if it has to descend the shorter shaft or drift soon after entering the mine; but unfavourable if it is first carried up the longer drift, according as the workings of the mine extend to the deep, or to the rise of the level. The effect in summer, on the contrary, will be most favourable when the air first ascends the shorter drift, and the contrary when it descends the longer drift on entering the mine. The arrows in the figures show the directions of the air-current, which is supposed to be losing or gaining temperature during its course; and by applying the reasoning given in preceding cases, the causes of these effects will readily appear.

Shafts.—In considering the equilibrium of the columns of air in the case of sloping drifts, or of shafts standing at different levels, it is essential to refer

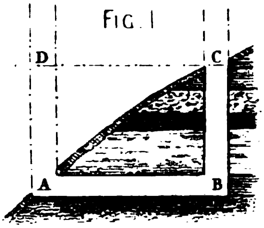


FIG. 1

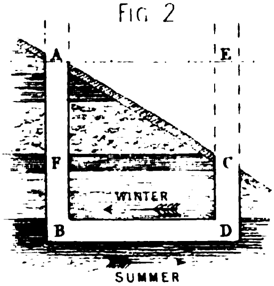


FIG. 2

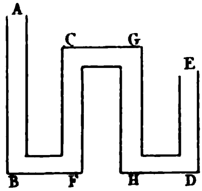


FIG. 3

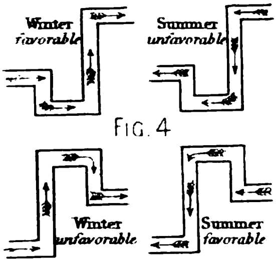


FIG. 4

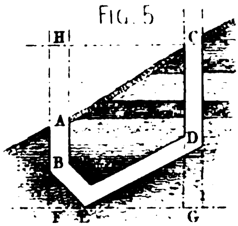


FIG. 5

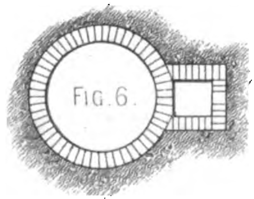


FIG. 6.

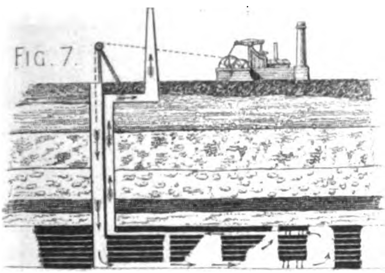


FIG. 7.

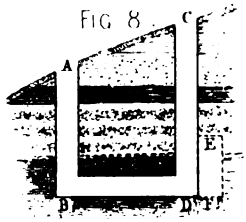
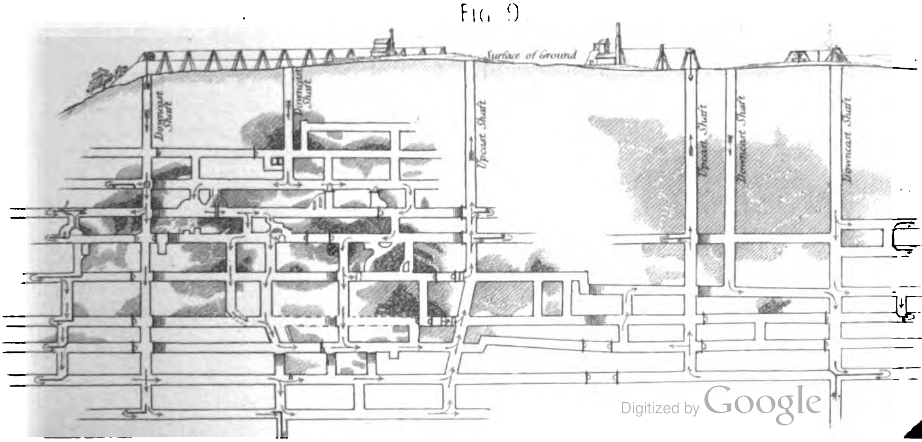


FIG. 8

FIG. 9.



them to the same horizontal lines. Thus the drifts B E, E D, in Fig. 5, Plate III., will be equivalent in their effect of producing motion to the extension of the shafts, by the depths B F and D G, subject to certain allowances depending on the extent of the surface of the drifts, the consideration of which belongs to another part of the subject. It is, therefore, obvious that the amount of natural ventilation depends more on the difference in level of the tops of the two shafts than on their relative depths, a circumstance well known in practice. For this reason, chimneys have been frequently erected on the top of shafts. Thus, at Liege the upcast shaft of a mine has been carried up with an internal diameter of 9 feet, in the form of a chimney 210 feet high. There are also two chimneys, each 180 feet high, at the Seraing works for the same purpose; and in consequence of the aqueous vapour and the gases taken up by the air-current, it is not found to reverse in the summer-time. The practice of contracting the upcast-shaft by a chimney of small diameter is clearly prejudicial, and has the same effect as would attend putting on a damper. Little benefit is derived from a high chimney unless the shaft is of small depth, for it is found that the amount of ventilation depends —all other circumstances being the same—on the square root of the depth of the shaft. Thus, if the upcast shaft of a mine is 400 yards deep, the addition of a chimney 123 feet high would only add 1·20th to the ventilation. A short stack of from 10 to 30 feet high, raised on the top of the shaft, is useful to protect the escaping air from the disturbing eddies which occur along the surface of the ground. Too much attention cannot be paid to the removal of all obstructions from the openings of the downcast and upcast shafts. Even where there are no winding carriages to intercept the opening, considerable increase of ventilation has been obtained by providing, close by, another short shaft, communicating with the main one below the platforms which form the top of the shaft.

The area of an upcast shaft to afford a given amount of ventilation, as well as the proportion which it should bear to the area of the downcast shaft, are subjects which have been discussed without leading to any very definite rule. In the upcast shafts of a coal-mine three hundred yards deep, and two hundred acres in extent, one square foot of area is usually allowed for every 1000 cubic feet of air per minute, which has to be passed up it by furnace ventilation; but it is possible, under very favourable circumstances, to obtain more than double this ratio of ventilation. The natural ventilation of the Tyne Main Colliery, before quoted, gave 760 cubic feet of air per minute for each square foot area of the shaft. By the highest furnace ventilation, this quantity was increased to 2020 cubic feet. When the shafts of a colliery are of equal depth, but different diameters, natural ventilation ordinarily converts the smaller shaft into the upcast; but when the air is highly expanded by a furnace, ventilation generally proceeds most easily by employing the larger shaft for the ascending air. Many circumstances, however, occur to vary these conditions; a wet or unwalled pit is unfavourable to its use as an upcast; and the best shafts are those which are circular and walled throughout with brick. A shaft divided by a partition or brattice, not only offers a large sur-

face to the friction and for the cooling of the air, by which the difference in temperature of the ascending and descending columns is lessened, but is also injurious to ventilation, in consequence of the leakage of air through the brattice, a defect which it is difficult altogether to prevent. The Monkwearmouth, and other collieries ventilated by brattice shafts, exhibit an inferior degree of ventilation. The system employed chiefly by Mr. Gibbons in South Staffordshire of carrying up a flue or chimney, generally about three feet by two feet, or two feet square in section, as represented in Fig. 6, Plate III., alongside the downcast shaft, by which the minerals are extracted, may be adopted from motives of economy in mines employing a number of persons not exceeding forty or sixty; but it is quite unsuited to mines of average magnitude, in consequence of the impossibility of forcing an adequate amount of ventilation through an opening which offers so much resistance. The diagram, Fig. 7, Plate III., represents a vertical section of the method of ventilating the thick coal seam in Staffordshire, which is thirty feet in height, by carrying the air returning from the workings through air-ways driven through the upper part of the coal into the bottom of the shaft-chimney. Still more objectionable is the practice of conveying air in pipes or air-trunks up or down a shaft. Some of these pipes may be occasionally seen surmounted by a coffin-shaped wind-box to face the direction of the wind—a significant indication of the destruction of health and life proceeding from the inadequate ventilation below.

The Motive Column.—We have already shown that motion of the air in two shafts connected by an air-way, is produced by the greater weight or density in the one than in the other; and that these unequal densities are due chiefly to differences of temperature. Now, if we ascertain by how much the pressure of the atmospheric column on each square foot of the base of the shaft A B (Fig. 8, Plate III.) is greater than the pressure on the base of the shaft C D, in which the air has been rendered lighter, and represent this difference in pressure by a column E F of the same temperature and density as the air in the shaft C D; then E F is termed the "motive column," and its height may be determined either from the known density and temperature of the air, or by observation with the barometer or water-gauge, in the same manner as in the case already described of a gas flowing out of a simple orifice in a vessel. If by t_1 and t_2 we represent the temperatures of the downcast and upcast shafts respectively, then,

$$459 + t_1 : 459 + t_2 = CD : CD + EF$$

from which we get generally that

$$EF = CD\left(\frac{t_2 - t_1}{459 + t_1}\right)$$

$$\text{and the motive column} = \text{depth of upcast}\left(\frac{t_2 - t_1}{459 + t_1}\right) \quad . \quad . \quad . \quad . \quad (1)$$

A body descends by gravity $16\frac{1}{12}$ ft. in the first second of time. By the law of falling bodies, the velocity acquired in falling from any given height

$$= \sqrt{4 \times 16\tfrac{1}{12} \times \text{height}}$$

It has been found that the velocity with which air would flow through the orifice in a vessel, or through the opening between two such shafts, would (provided there were no resistance, such as those arising from friction) be the same as that acquired by a body falling through the height of the motive column; therefore

$$\text{velocity} = \sqrt{4 \times 16 \times \text{motive column}}$$

and substituting the value already found for the motive column,

$$\text{the velocity of the flowing air} = 8\sqrt{\text{depth of upcast } \left(\frac{t_2 - t_1}{459 + t_1}\right)} \quad . \quad . \quad (2)$$

It is evident from this formula that the amount of ventilation circula in a mine is in proportion to the square root of the depth of the upcast, as well as to the square root of the difference of temperature between the upcast and downcast. Thus, if the temperature of a downcast shaft was 50°, and of the upcast 75°; by raising the temperature of the latter to 150°, the quantity of air set in circulation would be as $\sqrt{25} : \sqrt{100}$; that is, it would be doubled.

These formulæ do not include the variations of the density and temperature in the same shaft, nor the admixture of gases with the air. Exact measurements by the barometer are therefore necessary; and when the rarefaction of the upcast is produced by a machine, the estimation of the difference in pressure by this intrument, or by the water-gauge, is indispensable.

A very large proportion of the theoretical velocity is absorbed by friction against the surfaces of the shafts and air-ways, angles, and other obstructions. These resistances are found to be in inverse proportion to the sectional area of the air-ways, but in direct proportion to the square of the velocity of the currents. The resistance is also proportional to the surface exposed to the friction of the passing current—that is, to the length and the circumference of the air-way; but the nature of the surface exposed to the air materially affects the amount of friction. Experiments have been made by Peclet ("Traité de la Chaleur") and others, to determine the difference between the theoretical and actual velocities of the flowing air. If by D we represent the mean diameter of the whole of the air-course from the top of the downcast, back to the top of the upcast-shaft, and by L the length; then the

$$\text{actual velocity} = \text{theoretical velocity} \times 2{\cdot}06 \sqrt{\frac{D}{L + 4D}},$$

when the air-ways and shafts are lined with brick, and the former is very short in comparison with the latter; when the shafts, on the other hand, form but a small fraction of the run of the air-current after it leaves the surface, as is ordinarily the case in mines, then H being the height of the heated column of air, the

$$\text{actual velocity} = 2\sqrt{\frac{D}{L}} \times 8\sqrt{H \left(\frac{t_2 - t_1}{459 + t_1}\right)}, \text{ or } 16\sqrt{\frac{D}{L}} \text{ (motive column)}. \quad (3)$$

The quantity of air, or amount of ventilation, is obtained by multiplying the velocity by the mean area.

Splitting and Distributing Air.—It has been found that the amount

of ventilation which can be carried through the air-ways of a mine depends on the following conditions:—If the downcast and upcast shafts communicate by more than one air-way, the air-current is said to be split, and the quantity of air which will pass along each air-way is in inverse proportion to the resistances met with. If the air-ways are similar in area and section, the quantity or velocity of the air is in inverse proportion to the length of the air-way. Thus, if one split is four times the length of the other, the velocity of the air will be reduced to about one-half. If the air-ways are of equal length and similar section, but of different areas, the quantity of air passing through each will be in proportion to the areas. It follows that if the shafts are so large that we may neglect their resistances, the dividing the air-current into two splits will introduce double the quantity of air into the mine; and if we, at the same time, shorten the length the air has to travel, the ventilation will be further increased. If, for example, in improving the ventilation of a mine, in which the air is confined to one channel, 3600 yards long between shaft and shaft, the mine is divided into two districts, so as to require a ventilating air-way 2500 yards long for each, then the total quantity of air passing through the mine is not only doubled, but increased in the proportion of

$$\sqrt{2500} : \sqrt{3600} = 50 : 60.$$

If there are three splits 1600 yards long each, the ventilation would be multiplied four and a half times.

Although the air naturally "splits" itself into as many openings as the excavations present, the systematic application of this great modern improvement in the ventilation of mines is generally attributed to Mr. Buddle. Split air is said to have been introduced first at the Felling colliery, in 1815, by Mr. Hill. The air is confined to its course by stoppings, *i.e.* walls built across any abandoned openings, or by doors where access is required to either side of the current. The main stoppings frequently consist of brick walls set in mortar, filled in between and close stowed with rubbish.

As the resistance of the air-ways increases as the square of the velocity, it is found in practice undesirable to employ currents moving at the rate of more than five lineal feet in a second. Above this velocity the loss in ventilation augments rapidly, as well as the difficulty of preventing leakage through stoppings and doors. For a short distance before the splits separate, and after they re-unite, the size of the main air-way may necessitate a greater velocity; and the velocity in the upcast shafts occasionally reaches as much as thirty feet in a second. Three feet per second is a velocity adequate to remove and render harmless the ordinary discharges of fire-damp; but as half a foot in a second is already enough to deflect the flame of a candle, the former velocity causes the candles to "sweal" and burn quickly away, and it is seldom found in the working faces, except where safety-lamps are used. The test of perfect distribution of the ventilation in metalliferous and other mines which do not contain fire-damp, is the maintenance in every working place of a current slightly exceeding thirty lineal feet per minute, which will sensibly deflect the flame of a candle without creating inconvenience. It is found in practice, that to

effect this requires the introduction into the mine of 100 cubic feet of air per man per minute, which will allow for the unavoidable loss in leakage and in airing the old works. This corresponds with the quantity of air previously shown to be required to keep down the temperature of the working places, as well as for sanitary purposes. Thus, in a mine employing, when in full work, 200 men and 10 horses, the amount of ventilation required is $200 \times 100 + 10 \times 600 = 26000$ cubic feet per minute. Two intake air-ways, of at least 40 square feet area each, should be provided, and the upcast shaft, if artificially worked, should be at least six feet in diameter. According to Mr. T. J. Taylor, "the least amount of current should depend on the requirements of the mine; for example, in a mine which yields no fire-damp, with 120 or 130 persons employed in it, a current of 20,000 to 30,000 cubic feet per minute might be a fair quantity, if properly conveyed up to the face of the workings and made to sweep those districts where the people are employed; but in a fiery mine, much more than the quantity named would be required."

In mines giving off fire-damp, and which are efficiently ventilated, the quantity varies from 200 to 600 cubic feet per man per minute. When the old workings are extensive, an additional quantity of air should be allowed for rendering them safe; but generally the amount of escape of gases in the same mine, bears a constant relation to the number of men engaged in laying bare and removing the rock. The upcast shaft of the Hetton colliery passes, under ordinary circumstances, 200,000 cubic feet of air per minute by means of three furnaces. It is the largest ventilation known. The natural ventilation, when tried in winter, exceeded 100,000 cubic feet per minute. These results are obtained by the size of the shafts, 14 feet in diameter, and by the judicious distribution of the air into five main currents, which are subdivided into thirty-five splits. The extent to which splitting may be carried depends upon the size of the shafts, which, like the diameter and length of stroke of the piston of a steam-engine, determine, by their depth and area, the ventilating power of the mine.

The section of a Cornish mine, given in Fig. 9, Plate III., exhibits the mode of ventilating a perpendicular seam or lode, by converting four out of the six shafts into downcasts, and the other two into upcasts. The pure air in descending is carried at once to the working places; and then passing along the levels of the mine, takes up its temperature before reaching the bottom of the upcast shaft. The chief causes of the defective ventilation in metalliferous mines, are the leakage which takes place between the numerous shafts sunk in the same lode, and the distance to which the levels and shafts are driven beyond the circulating current. The latter evil is partly obviated by sinking winzes or short underground shafts, from level to level, at intervals of forty yards or less, as represented in the section. In working beds or seams, two or more parallel drifts or galleries are driven out in advance of the rest of the workings, leaving a pillar or a long block between, sufficiently wide and strong to resist any pressure which the removal of the spaces at its sides may bring upon it. This pillar is holed through at short distances to open a passage for the current of air to pass near to the face of the

work. As each fresh holing is opened, the openings are closed with stoppings.

The arrows point out the direction of the current of air, and the doors are marked D. The shading represents the portions of the lode excavated, the darker shading indicating the worthless debris heaped up in the deads.

In order to bring the current of air always up to the workman, a door is placed outside the last holing, and a plank or canvas partition is carried on from the side of the door to within four or six yards of the end of the drift, as represented in the sketch (Fig. 1, Plate IV.), where B is the door partly removed to show the partition or brattice A. The air enters by the space C, which should be kept as large and open as possible, and wider at the top than the bottom, in order that the greatest body of the entering air should, on leaving the brattice, be thrown along the roof, where the fire-damp chiefly accumulates. Occasionally, an air-trunk or pipe is substituted for the brattice; but unless a square foot or more in area, it is inadequate to introduce a sufficient quantity of air. The sketches (Figs. 2 and 3, Plate IV.) represent the mode of fixing two other kinds of brattices A A, one called "a soller" along the floor, and the other along the roof. As the air in a level usually has a tendency to enter along the floor, and return by the roof, this arrangement of the current should be preserved, and the circulation will be promoted. The doors in a mine are placed so as to open against the direction of the current of air, which therefore tends to close them. By setting the bottom of the door-post which carries the hinges about four inches outwards and the same forwards from the perpendicular, the door will always close of itself. Whenever doors have to be frequently opened, such as those on the main travelling roads, two doors are placed sufficiently far apart to allow of the train of trams standing between; so that one door being always shut when the other is open, the ventilating current should not be arrested. The leakage, however, which necessarily takes place through doors, renders the use of many prejudicial to the ventilation, besides being an indication of want of skill in the laying out of the air-currents.

In former days, the old workings of coal-mines were frequently left unventilated. To remedy this, Spedding of Whitehaven adopted the system of coursing the air; that is, carrying it by means of stoppings and doors up and down every part of the work open. A single current of air in the mine was thus extended to a length sometimes of forty or fifty miles. This has given way to the system now generally adopted of splitting. The panel or district of the works, represented in Fig. 4, Plate IV., is ventilated by a split of air, which is further divided into two splits—one being coursed through the lower headings and "bords;" and the other, after ventilating the pillars of coal which are in the process of removal, sweeps through the goaf which is on the higher side of the work. By larger air-ways and better furnaces, such large bodies of air are now introduced into coal-mines, that most of the doors can be removed which were required to complete the distribution of the air.

In laying out the ventilation of a mine, it frequently occurs that one current of air has to be conveyed across another. This is effected by a

"crossing," which may consist of one brick tunnel passing over another, as represented in Fig. 5, Plate IV., or the separation between the currents may be formed with timber or boiler plate. In fiery mines, where great disasters ensue from the separation being destroyed by an explosion, the latter material is desirable; but the sketch exhibits a method of building in half timbers into the arch, inverted in such a manner as to offer the strongest resistance to any force acting from above or below. When some of the splits of air are shorter or of larger area than others, too large a proportion of air would flow through them. Doors, with sliding panels or short walls, are placed, therefore, to obstruct the air-currents in these channels. They are called regulators. It is obvious that if the amounts of air passing along each split are thus equalized, the resistances in the long and the short split have been made equal, and that a considerable amount of useful work is absorbed by the regulators. It is, therefore, always desirable, if possible, to avoid their use by equalizing the length of the splits, or enlarging the area of that which is unavoidably the longest. In mines where the possibility of an explosion of fire-damp has to be contemplated and provided against, it is desirable so to construct any main regulator that it cannot be blown out, so as to cause the slackening or cessation of the air-current in other parts of the mine. To effect this, it can be built up in successive courses, as shown in the sketch; and sloping surfaces are thus presented to receive that part of the shock of the explosion which does not find vent by the opening. It has been suggested to suspend a light door A, as represented in Fig. 6, Plate IV., moving freely on an axis, to adjust any inequalities in the velocity of the current of air passing the regulator. The door is counterbalanced by a weight B, which can be adjusted from time to time, so as to afford the required opening for the current. As the current tends to increase, the augmented pressure on the door slightly closes it, and *vice versa*.

Artificial Ventilation.—*The Furnace.*—We have shown that the temperature of the rock of the mine, and other sources of natural ventilation, cause the air to ascend the deeper shaft in winter and to descend it in summer. During the stage of passing from one direction of the motion to the other, the air in the mine becomes, for days together, so far stagnant and fouled with noxious gases, that candles are extinguished and the workings stopped. These difficulties were experienced and partly surmounted in working coal-mines more than 150 years ago. They are now pressing severely on the economy of working in the deeper metalliferous mines; and doubtless, in the one case as in the other, necessity will ultimately teach, at a cost of life and property it is impossible to calculate, the simple means requisite for producing a uniform current of pure air at all seasons of the year. An arrangement like the Staffordshire mode of ventilation, already described, consisting of an air-pipe, or channel, at the side of the shaft, terminating in a chimney at the surface, was first adopted. A fire being lighted at the bottom of the chimney whenever the air was "dull" or "heavy," the ventilation of the mine was thus prevented from reversing.

The last of these contrivances in the Newcastle coal-fields existed at the

Felling colliery in 1812, when ninety-two persons were killed by an explosion; but they are unfortunately still too common in other districts. As the principles of natural ventilation became understood, it was found desirable to add, by artificial means, to those differences of temperature which caused it, so as to increase the ventilation or maintain it at a uniform rate, without obstructing the current by confining it in a narrow chimney.

The simple solution presented itself of consuming certain quantities of coal in the air-way near the upcast shaft, in such a manner as to insure the heat being taken up uniformly by the air, and as little as possible radiated or absorbed into the rock of the mine. For this purpose a furnace, varying from five feet to ten feet in width, is constructed in an archway of fire-brick, the bars being placed about one-fourth of the height from the bottom or floor. An air-space is left for the passage of some air round the outside of the arch, and water is allowed to stand in the ash-pit; whilst the main current passes above and partly under the bars: the heat which would be radiated into the rock is thus intercepted. The water being converted into vapour, increases the rarefaction in the upcast shaft. The drawing, in Fig. 7, Plate IV., represents one of the best forms of colliery furnaces for producing an equable ventilation, especially where the coal is much given to clinker and the bars have to be cleaned, whilst the pit is at work. Each furnace is fed with coal alternately. The amount of ventilation produced by a well-constructed furnace varies in practice from 4000 to 8000 cubic feet per minute for each foot in breadth of the bars. The bars are usually about six feet from front to back; but the first four feet are sufficient for the fire, which should be kept as thin as possible.

The furnace should be placed at a distance of thirty or forty yards from the shaft, so that the currents of air of different temperatures should be more uniformly mixed before entering the upcast. The furnace drift should begin to rise from the front of the fire, to accommodate the expansion of the air, and rise not less than one in six to the shaft. It is obvious that the area of the furnace drift should be larger than that of the other main air-ways of the mine. In ascending the shaft, the air parts rapidly with its heat. In a perfectly dry upcast shaft lined with fire-brick, the temperatures of the air at 25 yards and 100 yards from the surface were 188° and 207° respectively; in another shaft at the same depths, 104° and 135°: a loss, in fact, of about 1° for 10 feet in ascent, although the air was moving at a velocity of 11½ feet in a second. This will serve to explain the great loss sustained when the furnace drift is of great length, and when, as is frequently the case, it is contracted in area, and not carefully walled and arched in brick.

An example is given by Mr. Struvé, which is also represented in Fig. 8, Plate IV., in which a culvert 130 yards long, rising at an angle of 20°, provided with a furnace at the bottom, conveyed the air to another small furnace at the top, surmounted by a chimney fifty feet high. When the temperature of the external atmosphere reached 82°, the furnaces reversed, and the air descended. This will be explained by the sketch. The column of air in the workings 154 yards high at 63° plus the column of air in the drift 60 yards high, at a

PLATE. IV.

FIG. 1

FIG. 2

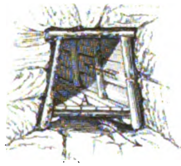
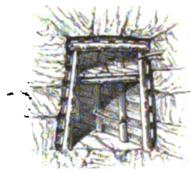


FIG. 3.



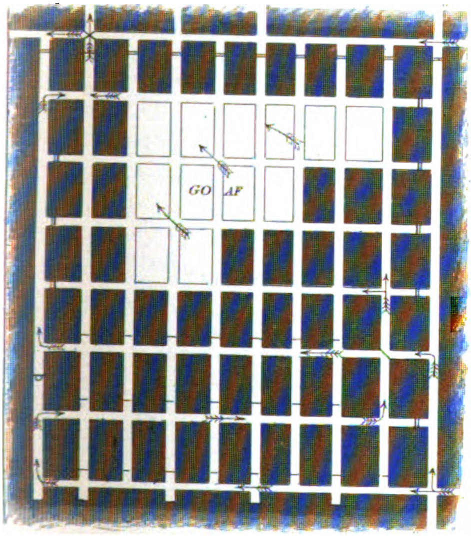
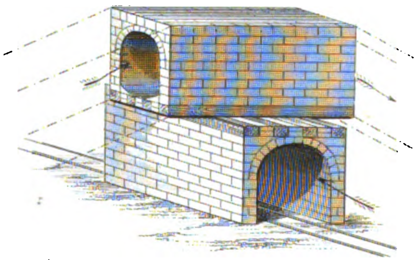


FIG. 4.

FIG. 5.



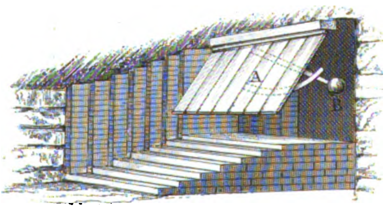


FIG. 6.

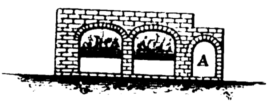
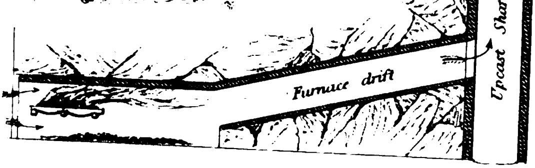
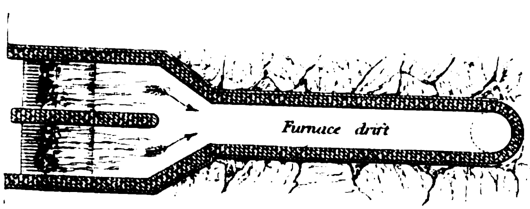


FIG. 7.





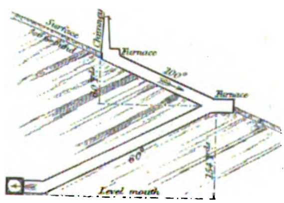


FIG. 8.

temperature of 100°, were heavier than a column of air of 214 yards in height and 82° in temperature.

It has been already shown that the amount of ventilation effected by a furnace is as the square root of the difference between the temperatures of the downcast and upcast shafts, and also as the square root of depth of the furnace from the surface. It is for this reason that fire-lamps hung a short distance down the upcast shaft are inefficient, and only admissible as a temporary expedient. Both fire-lamps and fire-places on the side of a drift are incapable of producing any considerable ventilation; as the consumption of coal is small, and in the latter case much of the heat passes into the rock and is lost.

The temperature of a furnace shaft is exceedingly variable, and so also the ventilation, though in a less degree. At the Morfa colliery (one of the most economical examples of furnace ventilation) 90 lbs. of coal were thrown on to a furnace 6 feet 2 inches wide, every quarter of an hour. The mean temperature of the ascending air 25 yards down the shaft, was, just before the coal was thrown on, 188°; two minutes after the supply of fuel, 196°; at three minutes again 196°; and 8 minutes after, 191°. The writer has met with instances where the ventilation has fallen from one-seventh to one-fourth in amount from the neglect of the man in charge of the furnace. In mines where the ventilation is barely sufficient to dilute the explosive gases, how many explosions, apparently difficult to account for, may have arisen from this cause! At the Cymmer colliery, where last summer 116 human beings were hurried into eternity, one of the foremen of the pit, on descending a short time before the explosion, found the furnace very slack. When the air returning from a mine is very foul,—that is, charged with fire-damp nearly up to the explosive point,—it flashes off in long flakes as it passes over the fire. The chemical affinity is raised by the heat; and these flakes of fire correspond to the cap upon the collier's candle. In all mines where there is a considerable discharge of fire-damp, the return-air containing the gas should not be carried over the furnace, but through a separate drift, called a "dumb-drift," into the shaft. This drift should enter the shaft at least 20 yards above the furnace drift, to prevent the possibility of the foul air becoming ignited. Regnault determined, in 1853, that the specific heat of air was ·2669 —*i.e.* that the same amount of heat which would raise 1 lb. of water one degree in temperature, would raise the same weight of air $.\frac{1}{2659} = 3{\cdot}75$ degrees; equivalent to raising 49 cubic feet of air by one degree. The average of the coals experimented upon for use in the steam navy, converted per pound of coal consumed under an ordinary boiler, 8·69 lbs. of water into steam; but according to the theoretical heating power of the average amount of hydrogen and carbon in the coals, each pound was equivalent to the evaporation of 13·775 pounds of water, or the heating by one degree of 674,975 cubic feet of air. At the Hetton colliery, three furnaces, one of nine feet and two of eight feet in width, gave a combined result of 11·066 cubic feet of air, raised 62° in temperature per pound of coal consumed, and 18·86 pounds were consumed on the furnaces per minute. The nine-feet furnace alone gave 16,320 cubic

feet of air raised 29° as the result for each pound of coal. The total effects in the two cases were equivalent to raising 686,092 and 473,280 cubic feet 1° in heat respectively. It is evident that the Hetton coal was of superior quality; but that the loss of heat in the furnaces and drift was very small. The average effect of one pound of coal may be taken as imparting one degree to 500,000 cubic feet of air.

It is an easy transition to proceed to calculate the theoretic horse-power of an upcast shaft, of which the area and depth are given; but it will be more satisfactory to compare the useful work done upon the air by the consumption of one pound of coal in an air-furnace, or under the boiler of a ventilating machine. It is first necessary to explain the modes adopted for arriving at the results.

Measurements of Ventilation.—The simplest method of measuring the amount of air passing along an air-way of uniform area, is to start from a fixed point and walk in the direction of the current of air at such a speed as just to keep upright the flame of a candle carried in the hand. The length travelled in one minute multiplied by the area of the air-way, is the quantity of air passing per minute. It is very desirable that the subordinate officers having charge of the ventilation should daily measure by a sand-glass, and mark on the wall, the distance they can thus walk in a minute in every split of air in the mine: no better instructor in ventilation could be found. As a velocity under thirty lineal feet per minute does not appreciably deflect the flame of a candle, this method is evidently only an approximation.

Powder-smoke is frequently used for the purpose. Powder is flashed off on the ground, and two observers mark the instants at which the smoke passes them. If the velocity of the last part of the cloud of smoke, as well as the first, is observed, the mean affords a close approximation to the true velocity. In the preceding methods, a considerable length of uniform air-way must be selected; but greater accuracy and convenience is gained by employing an anemometer, which requires only to be placed in several positions in any spot in the air-way to obtain the desired result. The form of anemometer generally used in this country is Biram's, which is illustrated in Fig. 1, Plate V. Each revolution of the vanes corresponds to one foot in the linear motion of the air, and is registered on the dial-plate. The velocity per minute multiplied by the area of the place in square feet, give the number of cubic feet of air travelling per minute. It is to be regretted that, from the construction of these six-inch anemometers, a current of 100 lineal feet per minute is required to set them in motion; in many ill-ventilated mines they are, therefore, useless. Combe's anemometer, on the other hand, being constructed with the lightness of watch-work, is set in motion by a velocity of only thirty feet per minute. The wheels A A that register the velocity, can be thrown in and out of gear with the worm B by means of the strings C C, whilst the four vanes D D are in motion. This instrument, which is generally used in the continental mines, is represented in Fig. 2, Plate V.

If air is forced through a long pipe by any machine, or drawn through it by some exhausting contrivance placed at the other extremity, the air will

be found gradually to decrease in density from the beginning to the end of the pipe; and the difference between the initial density and the density at any other point, will be a measure of the resistance opposed by the air-way up to that point. The difference of these densities may be ascertained by a water-gauge, inserted through the side of the pipe, such as is represented in Fig. 3, Plate V. The glass tube being open at each extremity, the difference of the water-level in the two branches of the tube measures the difference of pressure of the internal and external air. If the air of a mine is carefully measured by a barometer, the air will be found gradually to diminish in the same manner in its density or pressure from the bottom of the downcast to the top of the upcast shaft; but the simplest method of measuring the difference is to place the water-gauge through a door which serves to close some short channel between the bottom of the two shafts. The air in the galleries may be compared to a long spiral spring of extreme delicacy, drawn along the ground, or to springs connecting carriages in a railway train. The expansion at any point measures the resistance of the parts which follow. If the train is propelled before the power, the compression at any point measures the resistance of the parts which precede. If the difference of the level of the water in the tubes is one inch, then the weight of a square foot of water one inch deep being 5·19 lb., this is the total resistance offered on each square foot of the air-way to the passage of the air round the whole of the galleries of the mine. This is commonly called the "drag" of the mine. Multiplied by the area of the air-way, and then again by the velocity of the air—or, what is the same thing, at once by the quantity of air passing—the result is the amount of useful work done upon the air in forcing or drawing it through the mine. To this the resistances of the shafts ought strictly to be added. The water-gauge is not only a useful instrument for measuring the work done on the air, and instituting a comparison of ventilating powers; but by observing it, as well as the amount of ventilation, the person in charge of the latter can see the effect of his enlargements or splitting of the air-currents; and by a sudden rise in the water-gauge he will know that the fall of a roof or other obstruction in the air-ways, increasing the resistance of the air and diminishing its quantity, has occurred. A rise, on the other hand, might be caused by leaving open a door, thus giving the air-currents a shorter run.

At the Tyne Main Colliery, 34,955 cubic feet per minute were exhausted at a drag, measured by 0·2 inch of water, under natural ventilation, caused by a difference of 20° between the two shafts. The horse-power expended in effective ventilation was therefore—

$$\frac{\overset{\text{cub. ft.}}{34{,}955} \times \overset{\text{inches.}}{0{\cdot}2} \times \overset{\text{lb.}}{5{\cdot}19}}{33{,}000} = 1{\cdot}1 \text{ horse-power.}$$

By the consumption of 16·76 lbs. of coal per minute, which increased the difference of temperature to 94°, the useful work became—

$$\frac{\overset{\text{cub. ft.}}{101{,}876} \times \overset{\text{inches.}}{{\cdot}915} \times \overset{\text{lb.}}{5{\cdot}19}}{33{,}000} = 14{\cdot}66 \text{ horse-power.}$$

This is the power of a shaft 208 yards deep and 50 square feet in area. At the Hetton colliery the upcast shaft is 153 square feet in area and 900 feet deep to the three furnaces: a difference of temperature of 28° in natural ventilation produced—

$$\frac{\overset{\text{cub. ft.}}{127{,}145} \times \overset{\text{inches.}}{0{\cdot}55} \times \overset{\text{lbs.}}{5{\cdot}19}}{33{,}000} = 11 \text{ horse-power;}$$

and a difference of temperature of 86°, the result of the consumption of 18·86 lbs. of coal per minute, yielded—

$$\frac{\overset{\text{cub. ft.}}{208{,}466} \times \overset{\text{inches.}}{1{\cdot}2} \times \overset{\text{lbs.}}{5{\cdot}19}}{33{,}000} = 39{\cdot}34 \text{ horse-power.}$$

The Tyne main and Hetton shafts yielded 0·81 and 1·5 horse-power by the consumption of 1 lb. of coal per minute—a difference owing to the higher temperature, the unequal area, and the metal tubeing in the former shaft.

The average of the coals tried under the Admiralty boiler for 60 lbs. consumed per hour, evaporated 8½ cubic feet of water, equivalent nominally to 8½ horse-power. It follows, in this view of the question, that the Tyne main shaft yielded no more than 9½ per cent., and the Hetton no more than 17½ per cent. of the useful effect which the same quantity of coal is capable of yielding when applied under a boiler. A wide margin is thus left for the introduction of a more economical, if not more convenient, ventilating power.

It has been shown that in attempting to increase the ventilation in any colliery without altering the air-way, the resistance increases as the square of the velocity. Thus, if the velocity be doubled, the resistance will be four times as great, and the power expressed will become $2V \times 2^2R = 2^3VR$; consequently the power required to increase ventilation, the air-courses remaining the same, increases as the cube of the velocity or ventilation. But from the loss of heat at high temperatures, and other causes incidental to the employment of power, it should, in practice, be calculated that the fourth power, rather than the cube, approximates to the expenditure required in ventilation. It may easily be conceived that a practical limit is soon reached in the application of any ventilating power; but soonest, perhaps, in the case of the furnace, in consequence of the high temperatures and the small exhaustion, not exceeding in any mine 13 lbs. on the square foot, which it affords. But, on the other hand, if the ventilation is increased by splitting the air-current into two air-ways of the same area and length, double the power, in lieu of eight times the power, is all that is required to double the ventilation when the shafts are adequate in area. It is by carrying out this principle that the natural ventilation of the Hetton colliery exceeded the highest furnace ventilation at Tyne main.

An important deduction may be also drawn from the artificial ventilation being in one case double, in the other treble the natural ventilation; viz. that the air-currents should be arranged in accordance with the principle before

stated, so as to obtain the greatest assistance from the natural tendencies of the air.

The Steam-Jet.—Of the various ventilating powers, this is the most nearly allied to the furnace, when the steam is allowed to issue near the bottom of the shaft, for the temperature and aqueous vapour both aid in rarefying the ascending air. This is the chief effect produced by a blast-pipe; and although very convenient in the locomotive engine, where the run of the air is short and the exhaustion required small, it is unsuited to the efficient ventilation of a mine. The introduction of the steam-jet as a ventilating power, although instances are on record of its previous employment, is chiefly due to Mr. Gurney, who proposed it to a Committee of the House of Commons on Coal Mines in 1835. The action of the steam is variously explained. Mr. Gurney describes it as acting by impulse and a partial vacuum, others by the friction on the air carrying the latter along with it.

A single jet is represented in Fig. 4, Plate V. The orifice usually varies from ⅛th of an inch to ¼th of an inch in diameter. The steam forms a cone, which, with the last-named size of jet, and a pressure of 30 to 40 lbs in the boiler, is 1 ft. 6 ins. in diameter at 4½ feet from the jet pipe. Its most economical effect is obtained when it is surrounded by a cylinder not exceeding this diameter, and whose length is about eight times the diameter. Glepin found the maximum useful effect with a cylinder 8 inches in diameter and 3 feet long, when the steam was at a pressure of 75 lbs. It occupied also a prominent position in the investigations of the South Shields Committee, and the Parliamentary Committees of 1849 and 1852. The Seaton Delaval colliery was long quoted as a successful example of steam-jet ventilation; but as the temperature of the upcast was 130°—*i.e.* 88° hotter than the downcast, caused by four underground boiler fires and gas retorts consuming 24½ lbs. of coal per minute—it ought to be considered a furnace ventilation, rather than as effected by the steam-jet. According to the colliery measurements, 3274 cubic feet of air per minute were obtained for each lb. of coals—according to the Government Inspectors, only 1862 cubic feet; whereas we have seen that the Tyne main and Hetton furnaces gave respectively 6080 cubic feet, and 11066 cubic feet by the consumption of 1 lb. of coal per minute. The exaggerated views entertained of the economy of the steam-jet by some persons were exposed in the elaborate experiments of Mr. Glepin in 1844: but it is to the liberality and talent of Mr. Nicholas Wood that the mining world chiefly owes a series of experiments made in 1853, on a scale never before attempted. These trials on the largest mines in England, whilst establishing the true relative position of the furnace to the jet, have conferred great benefit by promoting the science and practice of ventilation. At the Hetton colliery, thirty-seven jets ¼ inch in diameter (in total area 1·81 square inch) exhausted the steam at 40 lbs. pressure from two boilers, with hemispherical ends 5 feet 6 inches in diameter, and 26 feet long, which evaporated 117½ cubic feet of water per hour, consuming for this purpose at the rate of 25½ lbs. of coal per minute. The jets were arranged uniformly in tubes in the area of the bottom of the shaft. The downcast and upcast air were respectively at

46° and 90°; difference, 44°. The quantity of air averaged 159,913 cubic feet per minute, at a drag of 4·15 lbs. on the square foot, equivalent to 20·12 horse-power of useful effect; and subtracting, as before, 11 horse-power, the work due to natural ventilation, the useful effect obtained from the jets, including the increased temperature, was 0·36 horse-power for each lb. of coals consumed per minute, one-fourth only of the economy of the furnace.

At the Tyne Main Colliery, sixty-one jets, each $\frac{3}{16}$ of an inch in diameter —united area, 1·68 square inch—were placed in cylinders 6 feet long, and 11 inches in diameter, close to the top of the shaft, the spaces between the cylinders being closed. Two boilers, 30 feet long and 6 feet in diameter, consumed 20·48 lbs. of coal per minute, and evaporated 109 cubic feet of water per hour, equivalent to the same number of horses-power.

Amount of ventilation	49,500 cub. ft. per min.
Water-gauge	0·4 inch
Drag on square foot	2 lbs.
Useful effect by jets and natural ventilation	3·114 horse-power
Useful effect by natural ventilation alone	1·10 " "
Useful effect by jets alone	2·014 " "
Useful effect by jets alone per lb. of coal consumed per minute	0 098 " "
Useful effect by furnace alone per lb. of coal consumed per minute	0·81 " "
Useful effect by jets and furnace together per lb. of coal per minute	0·428 " "

From the above statement it is evident that 109 horse-power expended in steam only produced 2·014 horse-power—less than two per cent. of useful effect. Using fuel as the standard of comparison, the economy of the furnace is eight times greater than that of the jet. By calculation, an addition of 20° to the temperature of the upcast by the consumption of 2 lbs. of coal per minute instead of 20½ lbs., would have yielded the same amount of ventilation, 49,500 cubic feet per minute.

The steam jet has been recommended as an auxiliary to the furnace. Probably no more favourable example could be found than the Tyne main shaft; and yet, although the maximum of feet obtained by the furnace was 102,500 cubic feet at 1·2 inch water-gauge, and the maximum by furnace and jets combined was 106,830 cubic feet at 1·25 inch water-gauge, the consumption of coal was increased from 16¾ to 37¼ lbs. of coal per minute. As we proceed with the examination of the other ventilating powers, it will, by comparison, become still more manifest that the steam-jet is one of the most expensive to maintain; but in consequence of the insignificant cost at which the jets can be applied to a shaft, it will often be a convenient mode to apply ventilation in the sinking of a shaft or other temporary object, where there is boiler power to spare. After an explosion of fire-damp, when, on acount of the danger of another explosion, the furnace is extinguished, the steam-jet may prove a valuable expedient.

Mechanical Ventilation.—Having thus passed in review two classes of ventilating powers, there still remain for consideration ventilation by

machines and by water. In instituting an economical comparison of the power expended and the useful effect produced, we will, for simplicity, continue to employ the same unit—viz., the consumption of 1 lb. of coal per minute—although subject to the variations or errors incident to the transmission of the power through boilers and engines of various construction and effectiveness, to the machines which alone operate upon the air. Mechanical ventilators may be classified into pumps, fans, screws, and pneumatic wheels. The duck machine of Cornwall and the Hartz, the two great schools of metalliferous mining, may be considered as the type of the first-named class. It was improved by Mr. John Taylor in 1810. Figure 5, Plate V., represents an inverted tube A A suspended from a beam, and working up and down in the water B. As the tube ascends, the valves C open, and it becomes filled with the air of the mine. In descending, the valves C close by their own weight, and the enclosed air is forced out through the valves D. An improved machine has been for many years ventilating the Marihaies colliery near Seraing. Two iron tubs or aerometers, each 11 feet 6 inches in diameter, are suspended to a beam allowing of a five-feet stroke. The velocity of each aerometer was 125 lineal feet per minute; and 11,500 cubic feet of air per minute were exhausted at a drag of 6¾ lbs. per square foot. Mr. Struvé of Swansea, by covering over the aerometers, so as to make them double-acting, and by placing the valves at the side, in order to reduce, by large valve-area, the enormous loss of power in the valves of the above machines, has succeeded in producing a machine far superior to its preceding types, and excellently adapted to ventilation and to the exhausting of large bodies of air. Figure 6, Plate V., represents this machine connected to a winding shaft B, which is closed at all times by the lifting covers C C. A is the aerometer performing its downward stroke; D D are the valves. It is evident that each aerometer is both exhausting from the mine and discharging into the atmosphere in all parts of its course. The largest ventilation hitherto constructed is at the Middle Dyffryn Colliery in South Wales. It consists of two aerometers, each twenty feet in diameter on an eight-feet stroke, which are therefore capable of exhausting 10,000 cubic feet of air by each stroke. It is expected also to make eight strokes per minute when provided with an engine adequate to the resistance of the mine. The following machines are now at work:—

Where situated.	Size.	Years at work.	Cost without engine.	Cubic feet of air capable of being exhausted per minute.
Eaglesbush Colliery, S. Wales .	two 12 ft. diam.	8	£300	17,000
Westminster Colliery, N. Wales .	two 17 ft. diam.	5	700	50,000
Pyle Colliery, S. Wales	two 16 ft. diam.	3	600	40,000
Mynyddbachyglo Colliery, S. Wales	two 16 ft. diam.	4	400	40,000
Millwood Colliery, Swansea . .	one 12 ft. diam.	7	200	16,000
Cwmavon Colliery, S. Wales . .	two 18 ft. diam.	—	800	60,000
Middle Dyffryn Colliery, S. Wales	two 20 ft. diam.	3	1000	80,000

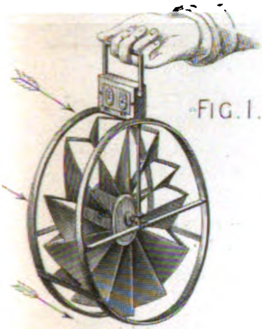
Fig. 7, Plate V., represents a section of a double-acting air-pump, applied by Mr. Briddle at the Hebburn colliery, when the discharge of fire-damp rendered the employment of a furnace dangerous. The cylinder was 8 feet and 5 feet square, and the piston made 30 strokes 6 feet in length per minute. Machines, with pistons of 11½ feet in diameter and counterbalanced valves, have since been erected at mines near Liege.

Fans.—The common straight-vaned fan, with air entering on each side of the centre, as in Letoret's fan, has been erected by Mr. Nasmyth, at the Skiers Spring and Abercorn mines. The fan at the former place is 6 feet in diameter, at the latter 12 feet. A better effect is produced by Letoret's fan, of which there are many examples at the Belgian mines. The sloping vanes A A are adjustable to angles of from 110° to 130° to the radius (as represented in Fig. 8, Plate V.), according to the velocity at which they have to be worked. B are the entrances for the air, at C is the connection with the upcast shaft, and D is the drum by which the fan is driven.

Figs. 1*a* and 1*b*, Plate VI., represent a vertical and horizontal section of the curved vane fan, invented and applied to several mines on the Continent by the Inspector-General Combes. A A are the curved vanes, occupying one-third of the circumference; B is the shaft. By calculation, the springing of the vanes ought to form with the radius an angle of 150°. The fan, which appears to avoid most of the sources of loss of power, is that represented in Figs. 2*a* and 2*b*, Plate VI. It was invented by Mr. George Lloyd of the Borough, and gained a medal at the Exhibition in 1851. At A is the communication with the shaft, at B the openings from it into the fan, and C C are the vanes, which occupy only one-sixth of the circumference. The throttling of the air in entering between the springing of the vanes, which causes the loud humming noise in fans running at a high velocity, is avoided by making the vanes wider at that point, so that the passage for the air through the vanes is of the same area throughout. The same result has been obtained in a conical fan contrived by the writer, and represented in Figs. 3*a* and 3*b*, Plate VI. A is the upcast shaft; B a hollow cone of sheet-iron, between which and the outer conical side C are the spiral vanes D D. There is less loss of the *vis-viva*, in consequence of the slight deflection undergone by the air-current; and by increasing the length in proportion to the diameter of the cone, a greater exhaustion or compression can be obtained than by ordinary fans.

Herburger's fan was applied more than twenty years ago to ventilation: it is represented in Fig. 4, Plate VI. It is similar to the fan invented by Mr. Brunton, but has this advantage, that each alternate vane B being shorter, there is less throttling of the air. The ingress of the air is prevented by a sheet-iron ring dipping into water at C.

Motte's Archimedean screw, represented in Fig. 5, Plate VI., was applied to the ventilation of mines, and was awarded a gold medal by the Belgium Academy of Sciences in 1840. Since that period a large number of ventilators, upwards of two hundred, of various kinds, have been applied in that country to the ventilation chiefly of the coal-mines, in which the seams of



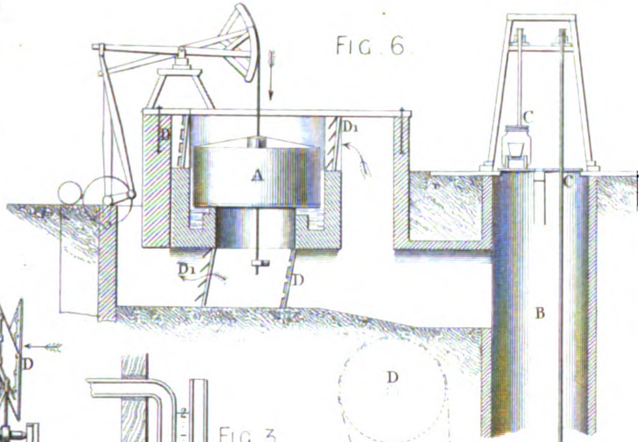


FIG. 6.

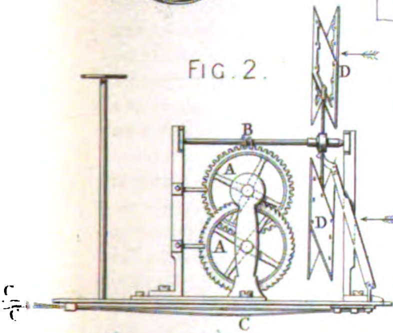


FIG. 2.

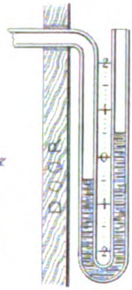


FIG. 3.

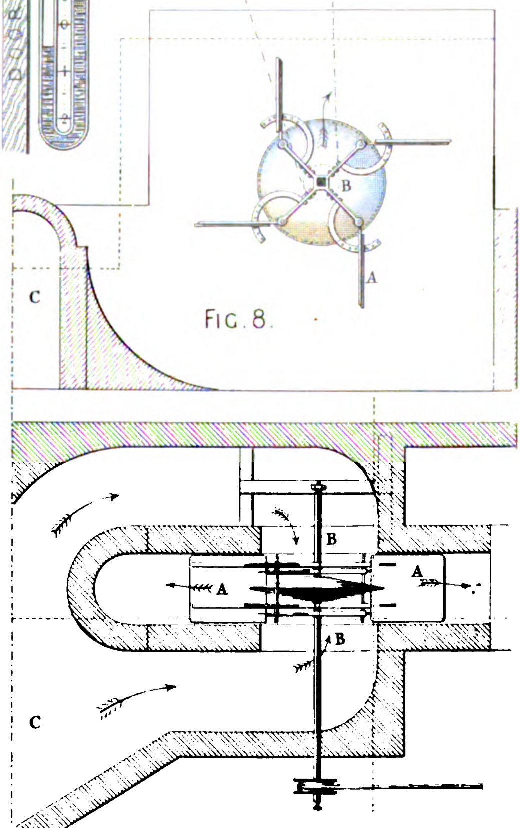


FIG. 8.

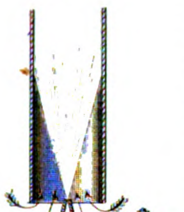


FIG. 4.

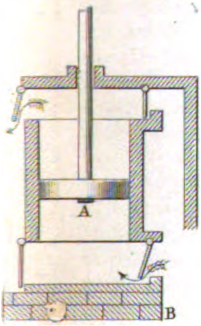


FIG. 7.

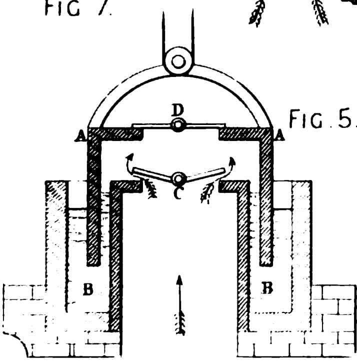


FIG. 5.

coal are extremely thin, and which lie at a high inclination, the air-ways being consequently small. Several kinds of ventilators, in form nearly resembling his anemometer, have been employed by Mr. Biram to ventilate collieries at Elsecar. Lesoinne's ventilator, in the Belgian coal-field, closely resembles it, the vanes being fixed at the angles given by Smeaton for wind-mill sails.

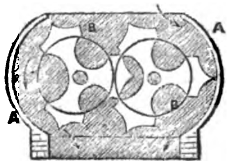


Fig. 6.

The two ventilators most frequently erected in Belgium are Fabry's and Lemielle's. The latter consist of two wheels revolving in opposite directions in a case A, by means of the external cog-wheels BB, Fig. 6. The cogs of one of these machines was 6 feet 6 inches in length, projecting 5 feet 7 inches from the centre, and was propelled by a 12 horse-power steam-engine, of 12 inch cylinder, and 2 feet stroke. The three teeth of the axle drives the air in the direction of the arrows, with a peculiar arrangement at the centre, which prevents its return. With the steam at 41 lbs., the number of strokes was 48; the quantity of air exhausted, 24,400 cubic feet per minute, at a resistance of 9½ lbs. per square foot. Its most economical effect was at 12½ lbs. The machine cost £176; with engine and boiler, engine-house, culvert, &c., £379. The annual expenses are—attendance and repairs, £47 16s.; coals, £61 16s.; total, £109 12s. Useful effect, 7 horse-power; and for each lb. of coal per minute, 2·8 horse-power. Fabry's machines are more used for forcing the air through the mine than in exhausting it. Mr. George Jones of Birmingham, claims the invention at an early date, of a machine similar in principle to Fabry's, but of greater simplicity, and in more perfect contact of the revolving pistons. It is represented in section in Fig. 7. Lemielle's ventilator bears much resemblance to the rotary steam-engine. Verzy's closely resembles it, being a cylinder flattened on two sides, revolving on an axis inside an air-tight case. To these flat sides are attached, by hinges, the shutters BB, which, by means of the connecting-rods moving round the eccentric axis E, are opened in passing the space C, and closed in returning by D. The air is thus propelled in the direction of the arrows. One of these ventilators at the Bois de Boussu, exhausted 21,000 cubic feet of air at an exhaustion of 4·7 inches, or 24·6 lbs. per square foot drag, equivalent to 16·6 horse-power of useful effect. A horizontal high-pressure engine of 14·8-inch piston, and 28-inch stroke, making 80 strokes per minute, consumed the power of 5 lbs. of coal per minute. The ventilators of Motte, Combes, Biram, and Brunton, are suitable for overcoming a drag of about 5 lbs. per square foot. Letoret's and Lloyd's fans can be worked up to

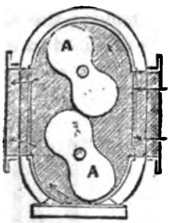


Fig. 7.

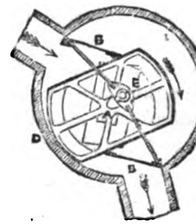


Fig. 8.

10 lbs.; the preceding machines are capable of being aided by any natural ventilation which may exist, and exhaust sufficiently to ventilate most mines where the air-courses are well laid out; yet, like all quick-motion machines, they exhibit a considerable loss of power.

Water Ventilation may be applied when there is an excess of pumping power in any mine, with an outlet for it by an adit level. Water where thrown into a downcast shaft after an explosion of fire-damp, or when the air becomes dull, aids the ventilation, by cooling the air. Mr. Greenwell found at the Blackboy colliery, that a fall of water from two holes, one inch in diameter each, to a depth of 126 yards, increased the ventilation in one of the districts from 8394 cubic feet of air per minute to 11,565 cubic feet. Figs. 9 to 12, represent in section four methods in which water has been applied to mine ventilation.

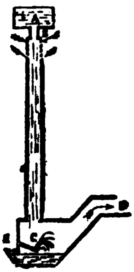


Fig. 10.


Fig. 9.

Fig. 9 is the water-trunk used in Cornish mines. The water flowing from A breaks on the iron bars B, entangling the air in its stream. The air passes off by the trunk D, and the water collects and overflows from the cistern C. Fig. 10 represents the water-blast (*trompe*) brought by the Moors into Spain, and used for blowing the Catalan forges. The pipe B, which the water enters in a funnel-shaped stream, regulates the discharge of water. The air enters chiefly by the holes just below; and when the water breaks on the block C, is forced through the air-trunk D. The waste water overflows at E. A great mistake is sometimes committed in making the air-trunk D too small. It is quantity of air, not velocity, that is required in underground operations.


Fig. 11.

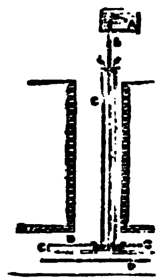


Fig. 12.

Fig. 11 differs chiefly from the last in the *vis-viva* of the falling water not being expended on the dashing-block, but distributed on leaving the aperture C, over the area of any shaft in which the water-blast may be placed. Fig. 12 represents the application of water-jets to the ventilation of a gallery extending 700 yards from the shaft. The air was brought down by the wooden trunks C C. The water entering the rose A passed down the one-inch gas-pipe B, and was discharged under ninety-four yards of pressure through the copper roses D D, placed in the centre of the air-trunks. The water issued like condensed steam from six holes of one-sixteenth inch diameter in each rose. The air attained a velocity through this great length of pipe of 600 lineal feet per minute, and kept the ends at all times clear of powder-smoke. The expenditure of water was short of six gallons per minute. The method is capable of great extension by arranging a series of pipes and jets in the area of a shaft, either to force or exhaust the air of a mine. No experiments have been yet made to determine whether a mine can be more economically ventilated by a pumping-engine than by other powers; but water escaping under

great pressure may be applied with signal advantage to ventilate the hot ends in metalliferous mines.

History of Mining Jurisprudence.—In the four years ending with 1854, there were 1009 lives sacrificed by 365 explosions of fire-damp, forming, however, hardly one-fourth of the deaths in coal mining (3972) during that period, on which inquests were held. It is probable that, with the exception of catastrophes arising from fire-damp, the accidents in metalliferous mines are at least as frequent; and in both, a greater number are permanently maimed or die in a short time from the consequences of accidents. Whilst inquests are held annually on 46 colliers out of 10,000, there are upwards of 700 annually injured. Had it not been for the effect produced on public sympathy by the harrowing details arising from the sacrifice of scores of lives in a few moments, by that most fearful of all destroyers, fire-damp, the necessity of providing against this, and the other destructive underground agents, by the application of modern improvements, would only now have been forcing itself on the attention of nations engaged in mining. Far removed as is the miner's workshop from the light of day and public observation, rarely visited by his master, and subjected to inadequate or incompetent supervision, legislative interference, if required in any case by public safety or sanitary necessity, is *a fortiori* demanded to lessen the unnecessary dangers which abound in those dark labyrinths from which spring the chief elements of our national wealth and greatness.

It was more immediately to an explosion at the Horloz mine, by which sixty-eight lives were sacrificed, that the improved mining code of Napoleon in 1813 is to be attributed. Napoleon's law of 1810 had previously abrogated the law (1791) of the National Assembly, which reserved to the Government all mines more than 100 feet in depth. By the newer enactment, which has been the framework on which the mining jurisprudence of several other mining countries has since been modelled, the right of granting concessions for all mines was reserved to the Government; and certain small dues, together with compensation for surface damage, were apportioned to the owner. A petition by the person seeking a concession, has to be adressed to the Prefect of the Department, or, in Belgium, to the Provincial Counsel, who satisfy themselves of the rights and capabilities of the applicants; and on their advice, and that of the Government engineers of mines, the Minister decides to whom and on what terms the concession can be granted. This power the Governments of the various countries have employed to impose certain conditions on employers for securing the due protection of the life of the workmen underground.

In our own country, the minerals have been generally the property of the lords of the soil, except such as contained gold and silver, which were, up to the reign of William and Mary, termed royal mines, and paid dues to the crown. The crown also holds many properties in the Forest of Dean, in which the system of granting concessions is not very dissimilar to that pursued on the Continent, except that provisions are not made for the safe conduct of the underground operations, other than may be arrived at by a

proper mode of extracting the minerals. As an illustration of the state of the mining population, and of the little attention paid to them, it may be quoted as a fact that, "previous to the year 1775, all colliers and other persons employed in coal-works were, by the common law of Scotland, in a state of slavery. They and their wives and children, if they had assisted for a certain period at the coal-work, became the property of the coal-master, and were transferable with the coal-work, in the same manner as the slaves on a West India estate were held to be property, and transferable on a sale of the estate. They were emancipated by 15 George III., c. 28."

Hardly less deplorable has been the condition of large sections of the mining population in other districts. Untaught, uncared for, and demoralized by truck, they had been abandoned and even encouraged in an excess of licentiousness and moral darkness, which are a blot upon the age.

It was only after the explosion at the Felling colliery in 1812, by which the unprecedented number of ninty-two lives were lost, and the publication of the report of a society then formed, "for the prevention of accidents in coal-mines," that Sir Humphry Davy was invited in August, 1815, to visit the north of England collieries, to suggest further precautions. In a few weeks he produced the Davy lamp, which, in simplicity and practical utility, has not yet been excelled.

The great Wallsend explosion, which hurried into eternity 101 more victims, ushered in the investigations of the Committee of the House of Commons, in 1835, who, after examining a large number of witnesses, reported that they declined to offer any recommendations, because they were unable to lay before the House any particular plan by which the accidents could be avoided with certainty. They recommended the reporting of fatal accidents to Government; ventilation, to displace deleterious gases, and render them no longer fatal to life; safety-lamps, as a precaution against apprehended sudden changes in the miner's atmosphere, and plans of the workings; whilst their strongest reprobation was reserved for the want of a sufficient number of shafts, and the employment of brattice shafts, which the slightest explosion may destroy. 2070 were the whole number of deaths in the preceding 25 years, of which the Committee were able to obtain information; and had they recommended any decisive measure to Parliament, a large number of the 12,000 lives lost since that period might have been preserved.

The valuable labours of the South Shields Committee followed the sacrifice of fifty-two lives at St. Hilda in 1839; entering into the detailed examination of safety-lamps, ventilation, infant labour in mines, the scientific education of officers of mines, and government inspection and jurisdiction. They reported "that such inspection and jurisdiction, for securing the fullest protection to the public interests, are perfectly compatible with the private rights of property and the freedom of trade; and that the principle has already been acknowledged and acted upon by the legislature with regard to railways, the professions, the manufactories, and some of the

trades; and is peculiarly applicable to mining, unlike the former, far removed from an enlightened public investigation." In 1842, the admirable Reports of the Children's Employment Commissioners for Mines were presented to both Houses of Parliament. They investigated, with great minuteness, most of the sanitary evils and the dangers to which the mining population generally are subject. Attention was chiefly directed to the long hours and severity of the labour of mining boys; to the accidents which arise from important duties being placed upon them, such as attending to ventilating doors and working engines; and to the seeds of disease and mortality produced by poor air, and wet or low travelling roads. Iron-stone mines were found to be less perfectly drained and ventilated than coal-mines, and therefore more intensely productive of physical deterioration; at the same time it was established that a coal-mine, when properly ventilated and drained, and when all the passages are of tolerable height, is not only not unhealthy, but, the temperature being moderate and very uniform, it is, considered as a place of work, more salubrious and even agreeable than that in which many kinds of labour are carried on above-ground.

Amongst the metalliferous mines, it was found that only in the Cornish district were many children employed underground. The primary and ever-active agent which principally produced the rapid deterioration of the health and strength of the miner, was the noxious air of the place in which the work is carried on. The ultimate effect of the disadvantageous circumstances under which the miner is obliged to pursue his laborious occupation, is the production of certain diseases (seated chiefly in the organs of respiration), by which he is rendered incapable of following his work, and by which his existence is terminated at an early period. The presentation of the report was followed by an ever-memorable speech from the Earl of Shaftesbury; and an Act (10th August, 1842) prohibiting the employment of women and girls in mines, and to regulate the employment of boys, was the first instalment of legislative justice vouchsafed to the prayers of many colliers' petitions. By the second section of the Act, boys must not be employed underground by the owner before they are ten years of age, under a penalty for such employment of not less than £5, nor more than £10; but any parent or natural guardian wilfully misstating the boy's age may be fined a sum not exceeding £2, whereby the previous penalty is rendered void. The third clause provides for the appointment of an inspector, an office since filled by Mr. Tremenheere, who, by his exertions for their social improvement, has gained the regard of the miners; and has suggested and promoted the prize schemes, by which the mine-owners in many parts of England encourage the continuance of boys at school, after the age at which they are now able to enter the mines.

The above Act further renders illegal the employment of any boy under fifteen years of age to take the charge of any engine, windlass, gin, ropes, chains, or other tackle, whereby persons are brought up or passed down any shaft or underground inclined plane. Any payments of wages on the premises of public-houses or places of entertainment, are of no effect; and the person

paying is liable to a penalty, because, as cited in the Act, "the practice is found to be highly injurious to the best interests of the working classes." The time had not yet come for dealing with the more serious defects in mines. The Royal Commissioners, Messrs. Faraday and Lyell, in 1844, inquired into the loss of 105 lives at Haswell, and into the explosion at Jarrow in the following year. Similar accidents at Risea, Oldbury, Coppull and Ardsley main, and the public feeling roused on every occasion, induced the Government to grant further investigations, leading to reports and recommendations almost identical in their more important features, but which passed unheeded by those responsible for the miner's security. The Committee of the House of Lords on Accidents in Coal-mines in 1849, again embodied, in a Blue-book of 615 pages, the evidence of the leading engineers from most of the mining districts. The value of the investigations made about this period was greatly enhanced by the reports of Mr. K. Blackwell and Professor Phillips, commissioners appointed by the Secretary of State to visit the mines, and to report on the means of remedying the defects existing in them. The last-named committee affirmed "that every witness, without exception, expressed an opinion more or less favourable to the establishment of a Government Inspection;" and in August 1850, an Act was passed for this purpose, which gave the right also to the Inspectors to examine mines and serve notices upon the owners respecting dangers to the persons employed. No power being granted for the remedy of any of the evils, the existence of which had been clearly established, Committees of Parliament were again occupied with the question in the years 1852, 1853, and 1854.

To aid them in arriving at some rules of safety which might be practically carried into effect at all coal-mines, a meeting took place, at their request, of representatives of the owners and managers of collieries from all the British coal-fields. After collating the colliery rules, several resolutions were passed, of which the chief were that a code of rules should be provided by the owner at each colliery, for the guidance of the manager and the workmen; and that an artificial means of ventilation should be provided at every mine, as well as at all times a sufficient current of air through the workings, to render innocuous all injurious gases. On the recommendation of the Committee, an Act was prepared and finally passed on the 14th August, 1855, embodying in a modified form some of the suggestions made; but leaving the most material provisions of safety to be framed by the owner of each colliery, under the name of Special Rules,—which, if not objected to by the Secretary of State, become binding on the managers and workmen. The general rules of the Act require shafts to be fenced, walled in dangerous parts, and provided with signals from top to bottom; that machines used for raising or lowering persons shall be provided with adequate breaks and indicators to show the position of the load in the shaft; and that to each boiler shall be attached a proper steam-gauge, water-gauge, and safety-valve. The other general rule, which relates to ventilation, is thus worded:—"An adequate amount of ventilation shall be constantly produced at all collieries, to dilute and render harmless noxious gases, to such an extent as that the working

places of the pits and levels of such collieries shall, under ordinary circumstances, be in a fit state for working in." The Act places the responsibility of the employer in a clearer light, and affords him all the power which he requires to enforce the observation of proper precautions. It applies only to coal-mines, which, however, find employment for more than two-thirds of the mining population; and it is an experiment, the success of which will be determined at the end of the five years' duration of the Act, by the owners having reduced the number of accidents in the same degree as has been effected by more precise rules, and more frequent supervision, in Continental mines.

In Belgium a commission, composed of Government engineers and directors of collieries, drew up an admirable code of regulations for the ventilation of every description of mine. It became law on the 1st of March, 1850. It commences thus:—"In every subterranean working, all the points to which the workmen can gain access shall be rendered healthy and safe by an active and regular current of pure air;" it also proceeds to require air-ways of proper dimensions, the isolation of vitiated currents of air, the maintenance of close stoppings, the carrying the air into the working faces, and the use of double doors. Other chapters enter fully into the ascensional ventilation, and the use of safety-lamps, which are compulsory in every mine containing fire-damp. It is remarkable that little attention has been paid in this country to ascensional ventilation, which, by Continental engineers, is considered the greatest modern improvement in the safety of mines. We have shown, that by carrying the air upwards through the mine after it had become heated in the working places, the ventilation is effected with the least expenditure of power. The heated or explosive gases assist rather than retard the current, and cannot accumulate. To carry the system out in its integrity, the upcast shaft should be carried as far as possible to the rise of the downcast shaft; if unavoidably otherwise, and the mine contains fire-damp, the return air should be conducted with a considerable velocity down the drift to the shaft, and all naked lights excluded from its vicinity. The descent of air, in places which give off fire-damp, is the cause of most of the dangerous accumulations of this gas which are found in mines. Most of the explosions can be traced to these accumulations; and yet the manager who neglects to remove them could not be more needlessly reckless of the lives of his fellow-creatures, if he left an open barrel of gunpowder in a dwelling-house.

Many proposals have been made by persons unacquainted with the working of mines, for drawing off accumulations of fire-damp from goafs by means of pipes, forgetting the enormous resistance offered to the passage of gases through pipes at a high velocity, as well as the constant destruction of the pipes which would occur from falls of the roof, from creep, and other causes. The operation of maintaining them in the goafs might be more destructive than the danger intended to be remedied. Cases seldom occur in coal-mining where, by a little additional expense. openings cannot be made along the upper side of these accumulations of gas, by which they may be dispersed. The special rules of most coal-mines contain a provision to the effect that all

accumulations of gas shall be removed with great care and without delay, but in no case until the men are out of danger.

An abundant and well-distributed ventilation does not necessarily secure perfect immunity from explosion of fire-damp. An extensive settlement of the roof, the intersection of a fault or a blower of gas, may give off at any moment a sufficient amount to bring the air up to the firing-point; and the accidental neglect of the ventilating power, the leaving open of a door, or the omission of the appointed officer to examine every working-place before the men enter, may cause the most disastrous explosion.

Complete immunity from this class of accidents is only to be obtained by superadding to good ventilation the exclusive use of properly locked Davy lamps in all mines, or parts of mines, where fire-damp is liable to occur in dangerous quantity. Blasting, except under special circumstances, and the passing of fire-damp over a furnace, are evidently unsafe. Out of 1099 deaths in seven years, reported by Mr. Blackwell, 72 occurred from underground furnaces, 1020 from naked lights, and only 7 from imperfect safety-lamps; the evidence being very doubtful whether these last should not be added to swell the preceding number. It is the opinion of many leading engineers that no fatal accident has ever occurred from a proper Davy-lamp. No higher tribute could be paid to human invention, and no reflection more severe on those who, after forty years of trial, reject its aid. Three-fourths of the victims, in the most destructive explosions, perish from suffocation. To avoid this, the workings of the colliery should be carried on in separate districts, or panels, separated by a barrier of coal, which limits the extent of the explosion; and the simplest means of restoring the air-current consists in providing, at all main doors, an extra door, ordinarily lying idle against the solid wall, but which can be closed as soon as the other doors are blown away by the force of the concussion.

At the Cymmer colliery explosion, by which 114 lives were sacrificed in July last, the flame extended 900 yards; and the after-damp, or irrespirable gases, produced by it, 1100 yards from the accumulation of gas which produced these disastrous results.

A large portion of the coal-mines, as well as the metalliferous, are, providentially, free from these drawbacks to mining enterprise; but in them a larger amount of injury and loss is inflicted on the workman by the insidious but certain destroyer, "poor air." Supervision is nowhere so lax as in underground operations; and education is nowhere more necessary in order to appreciate and remedy difficulties which have too long been left to chance. One is as important in the economical arrangement of the ventilation of a mine, as the other is indispensable to perfect and maintain it.

FIG. 1a

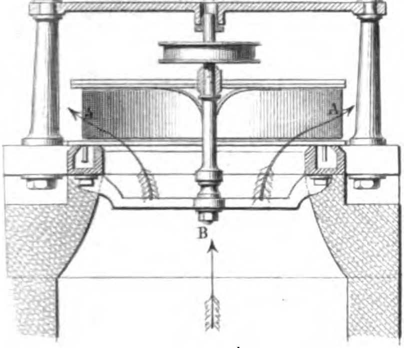


FIG. 2a

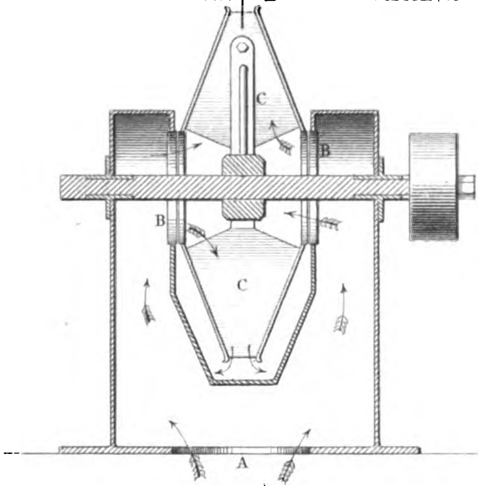


FIG. 1b

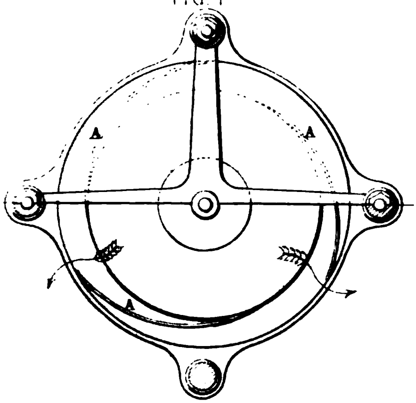


FIG. 2b

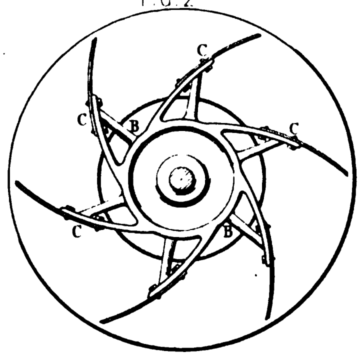


FIG. 3 *Section*

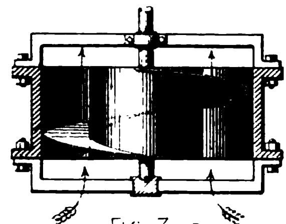


FIG. 3 a.b.

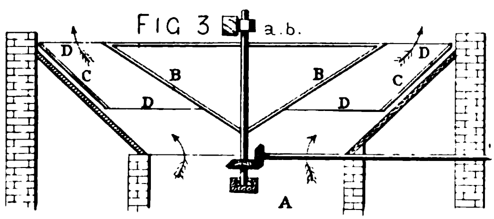
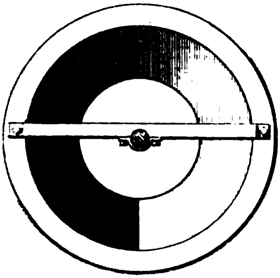
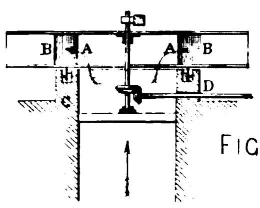


FIG. 3 *Plan*





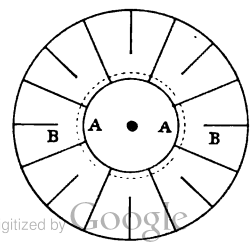


FIG. 4

CHAPTER VII.

HISTORY OF BRITISH METALLURGY.

We have no records of the state of the iron manufacture of Britain previous to the Christian era; and for several centuries subsequent to this period, it is involved in much obscurity. That the conversion of iron ore into malleable iron was known to the ancients, is evident from the Sacred writings. In the Old Testament mention is frequently made of this metal; and of Tubal Cain, the seventh direct descendant from Adam, it is recorded that he was "an instructor of every artificer in brass and iron." This demonstrates that only a very brief period elapsed between the creation of the human species, and the discovery of the art of fashioning instruments of warfare and cultivation out of this universally diffused metal. From the eastern nations the art travelled westward, and probably reached Britain through the Phœnicians, who traded with these Islands for tin at a very early period.

At the date of the first Roman invasion under Cæsar, fifty-two years before the Christian era, the English were acquainted with primitive modes of manufacturing iron, and had attained considerable skill in the art. Under the Roman dominion it appears to have increased, as evidence of extensive workings about this period is found in several districts, especially in the western parts of Somerset, Dorset, Gloucester, and Monmouth. With the abandonment of Britain by the Romans, about A.D. 426, and its subsequent invasion and conquest by the Saxons in 455, the manufacture appears to have greatly declined. Occupied in internal dissensions, or in repelling foreign invasion, the inhabitants bestowed a lesser portion of their time on the cultivation of the useful arts; and the iron manufacture apparently was limited to the production of instruments of warfare. In this state the iron manufacture remained several centuries, with little amelioration.

At this period, iron ore was converted into wrought-iron, by a process identical in principle with that followed at the present time in the manufacture of iron by several foreign nations. The broken ore, mixed with charcoal fuel, was subjected to a deoxydating process; the agglutinated mass resulting from this treatment was balled up and hammered into what is denominated a bloom; this being re-heated, was again hammered until the desired effect was obtained.

The discovery of gunpowder, and its application to warfare in the fourteenth century, appears to have caused, indirectly, a very great improvement in the iron manufacture. Hitherto, the object had been limited to the production, in small quantities, of malleable iron made direct from the ore; the requirements of the heavy ordnance which soon began to be used in warfare, demanded masses of iron of considerable magnitude. The period at which the art of

casting iron was invented, is not known. The first cannon were composed partly of cast and partly of wrough-iron; which latter in their turn were supplanted by cannon composed entirely of cast-iron. The casting of heavy ordnance gave a great impetus to the iron manufacture, and materially tended to its development in districts where, previously, it had only a languishing existence. This development was largely increased by the rolling-mill, one of which was erected in England by a foreigner. Sussex became an important seat of the manufacture, and continued to retain this position until the scarcity of timber threatened to put a complete stop to the numerous furnaces and forges. The destruction of the forests proceeded with such unabated rapidity, that the latter part of the sixteenth century witnessed the passing of Acts of Parliament restricting the consumption of wood as fuel, and defining the kind permitted to be used in the iron manufacture. This led to the stoppage of many works, and the curtailment of the trade to such an extent, that the exportation of iron was rigorously prohibited, lest there should not remain a sufficiency for home use. For some reason not very apparent, the timber of Sussex, of the wold of Kent, and certain parts of Gloucestershire, was exempted from this protection; to which circumstance the present comparative absence of timber in these localities is attributable.

Early in the seventeeth century we find recorded the first attempts at smelting with pit-coal. Mr. Dudley, of whom there is little known except in connection with the iron manufacture, obtained a patent about 1620, under which he proceeded to smelt with this fuel. His efforts were attended with success. Iron appears to have been made in considerable quantities, and at cheaper rates than previously. The entire applicability of mineral fuel to smelting having been practically demonstrated by Mr. Dudley's experiments, the proprietors of charcoal furnaces took alarm at the speedy termination which threatened the manufacture by that process; and combining together, endeavoured to prevent further extension in the new direction; and for a few years they succeeded in controlling its progress: but on the expiration of Mr. Dudley's patent, several persons embarked in the smelting of iron with pit-coal fuel. Failure for the most part continued to attend their efforts, until the early part of the eighteenth century; when, after encountering many disappointments, and surmounting the difficulties usually attendant on bold innovations on existing modes, the manufacture of iron with pit-coal was permanently established. At this period, also, the art of rolling iron into plates between steel cylinders came into use.

During the second half of the eighteenth century, the iron manufacture remained in a transition state. Charcoal was gradually being discontinued as a smelting fuel, its place being supplied by coke. Districts hitherto celebrated for their numerous forges and furnaces lost their importance with the exhaustion of the forests; and dwindled into comparative insignificance, while the manufacturers transferred their skill to localities favoured with an abundant supply of cheap coal. Smelting furnaces were rapidly constructed on the skirts of such of the coal-fields as appeared to offer a continuous supply of these great elements of success—good fuel, ore, and flux; for it

was soon found that the clay iron-stone was in most instances contiguous to the coal-fields. The iron industry of the kingdom concentrated itself around the hills of Gloucester, Monmouth, Glamorgan, Salop, Worcester, and the west of Scotland; and spots hitherto nearly uninhabited, being found to contain the elements of boundless wealth, and prosperity, in their coal-fields and accompanying ores, became crowded and populous districts.

The invention of the steam-engine, and its subsequent adaptation to the wants of the iron-smelter, led to other important improvements. Hitherto the manufacture of iron could only be carried on with profit by the assistance of water-power, to set in motion the wooden bellows used in the blast furnaces, or in working the small cylinders for compressing air which subsequently took their place. This necessity of water-power resulted in the establishment of many of the furnaces in localities at too great a distance from the minerals for obtaining the necessary supply of ore cheaply. The mountain streams also thus turned to account were liable to frequent changes of volume; the manufacture was thus extremely precarious, depending entirely upon the state of the streams. With the application of steam for working the blowing apparatus, however, the manufacture steadily progressed. Iron cylinders, at first of small diameter, were introduced, and finally supplanted altogether the old wooden apparatus in England. In some of the more remote American States, machinery of this primitive construction is still very common; while in others, the inventive genius of the people has introduced contrivances equal to our own. It was soon found that by proportioning the relative capacities of the two cylinders of the engine, the quantity and density of the blast could be increased to any desired amount The effect of this was seen in the augmented produce of the blast-furnaces then at work. In the beginning of the eighteenth century, some of the pit-coal furnaces made six or seven tons per week,—a quantity which was increased after the discovery of steam-power to twenty, and in some instances to so large a quantity as forty-five tons, in a single week.

This period of the manufacture is distinguished also for the invention of puddling cast-iron, to which the world is indebted to the late Mr. Cort. By the adoption of this process, the conversion of the iron into malleable bars was effected with less waste of material and at smaller expense than previously. The application of grooved rollers—also the invention of Mr. Cort—to rolling the iron, previously subjected to the puddling process, advanced the manufacture another step.

The first twenty-five years of this century produced no great improvements in the iron manufacture. The first ten or twelve years were years of unusual prosperity; manufacturers obtained prices for their iron higher by several pounds per ton than has since been realized. Years of great prosperity are commonly barren of important inventions, keen competition and low prices being, apparently, required to stimulate invention. Minor improvements were made in the processes of puddling and rolling; but the system of smelting remained nearly in the condition it so suddenly attained, consequent on the application of steam to propelling the blowing-engines. The water-

regulator, for equalizing the pressure of the blast in the intervals between the strokes, was, however, finally abandoned at this period; the moisture conveyed from its surface into the furnace being found infinitely more injurious than the small irregularity in the stream of blast which it was intended to regulate. More powerful engines were constructed and larger furnaces built, by which means the produce of the furnaces was largely augmented, especially in the South Wales district. In the district next in importance, namely, Staffordshire, the increase was much smaller; while the furnaces of Scotland remained nearly stationary as to produce and arrangements.

In the second twenty-five years of the century, the accidental discovery of the hot blast by Mr. Neilson, and its subsequent application to the Scotch furnaces, placed these nearly on a level with the more southern districts. The force of example also induced other proprietors to follow the improved Welsh models, with a corresponding economy of fuel. An accidental discovery made a few years subsequently also led to the adoption of an improved model of furnace, by which raw coal could be advantageously substituted for coked coal. No sooner, however, was this improvement in the form of the furnace adopted, than it was ascertained that the advantages resulting from the use of the hot blast had become less apparent; nevertheless, this invention forms a link in the history of the Scotch iron trade. The low percentage of the Scotch earthy carbonates led to trials of a carbonaceous ore previously considered worthless, and a very few years later this mineral formed the chief ore supplied to the blast-furnaces of Scotland; while its fusible character, and the facility with which crude pig-iron could be smelted from it, caused a sudden augmentation of the trade to five or six times its former magnitude.

The rapid development of the railway system at this period produced its natural result on the iron manufacture, forcing up prices to higher rates than had prevailed for thirty years. New works started into existence in every direction, while old ones were enlarged; and such was the activity displayed, that in five or six years the annual production of iron was nearly doubled. A temporary cessation of railway works, a few years back, resulted in great depression; but the low prices which ensued were ultimately beneficial, inasmuch as they placed iron in advantageous competition with wood for shipbuilding, with stone and timber in bridge and house-building, and generally with all other constructive materials; while the direct progress of Continental, American, and Indian railways, has helped to keep up the interests engaged in this important manufacture.

For many years attempts had been made to smelt with anthracite coal, of which South Wales contains a large quantity, but unsuccessfully. Iron had been made in Pennsylvania with this fuel, and elaborate experiments with a view to its adoption had been conducted in France, without leading to any commercial result. Mr. Crane eventually succeeded, after several failures, in smelting with this coal; but through inattention to the principles which should guide the smelter in its use, anthracite has never made progress in this country, although its close resemblance in construction to charcoal renders it so valuable, as we shall see in other countries; the consequence is, that at this

day a majority of the furnaces erected for its use have returned, in part or wholly, to coke of bituminous coal.

The high prices of iron consequent on the railway excitements of 1836 and 1845, led to the mining on an extensive scale of the ores of Lancashire, Cumberland, Cornwall, North Wales, Dean Forest, and other localities, for use in the South Wales and South Staffordshire furnaces; and an extensive trade sprang up in these districts, which subsequent years have greatly enlarged. Several minor improvements and alterations in the manufacture were also perfected, which gave increased facilities to its progress; running the iron into the refining furnace—refining in reverberatory furnaces, subsequently improved to working the molten iron direct from the smelting furnace—running the refined iron into the puddling furnace—straightening bars by machinery—squeezing instead of hammering the puddle blooms—the use of circular saws for cropping the ends, and several other modifications of scarcely less note, may be reckoned among these improvements. The produce of many of the blast furnaces of Scotland, Staffordshire, and South Wales, was also increased to an average of nearly 100 tons weekly; while in a few instances nearly twice this quantity has been obtained.

The half dozen years of the third period of the century are chiefly remarkable for the attention paid to the oolitic ores of the Northern and Midland counties. Several works have been erected in their vicinity; and it is anticipated that in a few years a large proportion of the iron for castings, and other purposes, will be derived from the new districts. Mr. Warrington Smyth, in his recent survey of the mining fields of the North and Midland districts, states the number of furnaces in blast to be as follows:—Northumberland, Durham, Yorkshire, Cleveland, Lancashire, and Derbyshire, 125; representing, in plant and buildings alone, a capital of half a million sterling.

HISTORICAL REMARKS ON COPPER MINING.

Copper is one of the metals known to the ancients, though it is not certain that the metal mentioned in the Book of Moses was the same as the pure copper of modern times. For a long period in the history of the world, this metal appears to have been used as the chief ingredient in an alloy in which tin played a secondary part. This alloy—melting at a lower temperature than pure copper—was also capable of being worked with greater facility than iron: in consequence, it was very generally used for instruments of warfare, of agriculture, and of art, by nations of antiquity. By attention to the relative proportions of the ingredients, the qualities of hardness, temper, and elasticity, seem to have been controlled to an extent seldom attained in any modern alloy of tin and copper.

The historical records of this metal are even more scanty in the ancient writings than are those concerning iron. The earliest copper mines on a large scale of which we read, appear to have been worked by Greeks in the island of Cyprus; whence it is probable the name copper, in Greek *κυπρον*. The quantities wrought so far back as 700 B.C. must have been considerable, as in the succeeding centuries the formation of bronze statues was very

prevalent. Rhodes, Delphi, and Athens, appear to have contained several thousand, varying in weight from a few hundredweights, to dimensions exceeding those of any modern casting.

From the breaking up of the Roman Empire to the commencement of the thirteenth century, we are without any authentic account of the progress made in working this metal. There is every reason for believing that, in these the dark ages of metallurgical science, the arts of copper-mining and smelting were well-nigh extinguished, and that the requirements of warfare were supplied by melting down the statuary bronze of the Romans and Greeks. In England, the earliest reference to copper mines dates from the middle of the twelfth century; when a patent was granted for working certain mines in Cumberland. In the four succeeding centuries, the production of copper was encouraged by bounties, and the exportation of the metal prohibited under severe penalties. This is indirect evidence of a comparative scarcity of copper; a result probably of the increased attention paid to the working of iron, when it had advanced so far as to produce ordnance, as well as goods of wrought-iron and steel. However that may be, about the end of the seventeenth century we find the Cornish mines producing small quantities of ore, which was bought up by smelters from Bristol and adjacent places. The production appears to have been under 1000 tons per annum; and any very large increase was prevented by difficulties attendant on the drainage of the mines after a few fathoms' depth had been attained. For many years the production remained nearly stationary; the average produce in 1730 falling within 2400 tons; from this period of inactivity, however, it rapidly increased, and we find the produce nearly 60,000 tons at the end of the century.

This remarkable increase was consequent on the greater depth to which the mines were prosecuted when available drainage power was discovered. In the seventeenth century, attempts had been made to use steam for this purpose; but it was not till the beginning of the eighteenth that steam-engines were adapted successfully to mining operations. The pressure of the atmosphere, obtained by creating a vacuum under the piston, was the power first used in the Cornish engines; and the most successful on this principle appear to have been devised by Newcomen. Imperfect as these engines confessedly were, it is not too much to say that their imperfection arose as much from the comparatively rude condition of manufacturing engineering at the period, as from defective principle. However that may be, with the aid of Newcomen's engines, mining was prosecuted for many years, and the production of copper rose from 2400 to 30,000 tons annually. At a later period, Smeaton improved this form of engine, and erected one with a cylinder seventy-two inches in diameter for draining one of the Cornish copper-mines. The discovery by Watt of the principle of condensation in a vessel separate from the working cylinder, led to a great economy of fuel, and thus enabled comparatively poor mines to be worked with profit. Hornblower improved on Watt's engines by using the steam expansively; and a few years afterwards, Trevethick introduced high-pressure steam. The inventions of these two mining engineers were rapidly adopted; and in twenty-five or thirty years the

consumption of fuel—the most costly item in drainage—was reduced to one-fourth of its previous amount.

With the reduced cost of draining mines by high-pressure, expansive, and condensing engines, machinery has been applied to some other operations. The adoption of the crushing-mill, tram-road, machine-wrought ore-cleaning apparatus, and inventions of lesser note, has resulted in a corresponding large saving of manual labour.

The nineteenth century has witnessed a further remarkable increase in the production of copper. Devon has contributed largely to the general stock, while Wicklow in Ireland, and Anglesey in Wales, have produced large quantities of ore, in conjunction with minor districts; raising the gross produce of Britain to more than 200,000 tons. Discoveries were made of large deposits on Lake Superior, and other districts of America, such as New England, New Jersey, Pennsylvania, Oregon, and North Carolina, where it is found native. In the Cliff Mine on Lake Superior, masses of iron have been found, weighing eighty tons, in the trap or sandstone rock. It is also found in the island of Cuba, in the Chilian provinces of South America, and, still more recently, valuable mines have been found in South Australia, which have tended to supply the increased demand for the metal, resulting from the advance of engineering and the arts. Much of the colonial ore is reduced near the mines, and consequently does not appear in the home trade. The same may be said of the Norwegian, Saxon, German, Hungarian, and other foreign ores, which are only mined in small quantities. It is in England, however, that the greatest copper manufactories are established; and however rude and antiquated many of the processes still pursued at home may be, foreign manufactured copper is still less valuable than English.

Lead.—Lead is one of the metals known to the ancients, being mentioned in the Books of Moses. For a very long period, however, the production of this metal must have been small, and we have no authentic records of the progress made in its manufacture previous to the Christian era. It seems highly probable that the Eastern nations obtained their principal supply from Spain and Britain, along with the more valuable metal tin; as explorations, bearing evident traces of great antiquity, have been discovered on lead veins in Wales, Derbyshire, and Northumberland. Lead mines abound to a limited extent in France, Bohemia, Saxony, and other parts of Europe; but in the majority of these countries the prosecution of lead mining is a modern branch of industry of very limited extent. In England, the most productive mines are in Durham and Northumberland; Cardiganshire, Derbyshire. Yorkshire, and Cornwall, produce considerable quantities of lead. At the commencement of the present century, the production in this country scarcely averaged 10,000 tons annually; but at the present time, several minor districts contribute, along with Scotland, Ireland, and the Isle of Man, to produce annually a supply of nearly 100,000 tons of lead ore, or of 78,000 tons of metallic lead.

The large increase which has taken place is referable to circumstances similar to those which influenced the progressive increase in the copper

trade; such as improved mining machinery, rendering the prosecution of deep mines profitable, the adoption of roller grinding mills, stamping mills, and machine-wrought washing apparatus, resulting in greater economy in the dressing of the ores. Every reduction of cost in dressing has given an impetus to the exploration of veins previously considered too poor to bear the attendant high dressing charges. The most important modern invention connected with this metal is the de-silvering process of Pattinson; by which the silver, commonly found to the extent of three to thirty ounces per ton of lead ore, is extracted in an inexpensive manner. By this de-silvering process, more than 500,000 ounces of silver are annually obtained from British lead ores.

The produce of lead in Great Britain amounts to fully two-thirds of the produce of Europe. Spain stands second, producing about one-third as much: united, the production of these two states is equal to seven-eighths of the European produce. The lead deposits of the United States extend upwards of three thousand square miles in the States of Missouri, Illinois, Wisconsin, Oregon, North Carolina, and California. A few years since, the western states of North America produced large quantities of lead—as much as 40,000,000 of pounds have been produced in 1851; but the deposits opened out, it is said, have not continued equally productive in depth; and their present comparative poverty is demonstrated by the large importations of British lead into these states.

Zinc.—This metal was first obtained in a metallic state early in the sixteenth century; but for a long period subsequent to its discovery, the production of metallic zinc as one of the useful metals remained in abeyance. Calamine, a carbonate of the metal, was employed in the crude state for alloying copper in the production of brass. Although we have no evidence to show that the ancients were acquainted with any process for manufacturing zinc, Pliny mentions the use of calamine in the manufacture of brass; and modern analysis of ancient alloys, indicates the presence of zinc. The great affinity of zinc for oxygen at low red heat, prevented an earlier acquaintance with it in an isolated form, and rendered its production, relatively to the cost of the ore, a comparatively expensive process. When its properties became better understood, the manufacture of metallic zinc rapidly extended. By carefully regulating the temperature employed, it was discovered that sheets, tubes, and useful alloys could be made with this metal, instead of the costlier metal, tin. The discovery of this single property alone, resulted in the adoption of zinc in arts and manufactures to a large extent; while its comparative non-liability to oxydation at low temperatures has caused it to be used as a protection to iron when exposed to atmospherical influences.

The production of zinc in England is not considerable—probably under 3000 tons annually. Germany and Belgium produce large quantities, and principally supply the growing demand for this metal. So great, however, is its affinity for oxygen during its reduction to metal, that, with the most improved plans yet adopted, a loss of one-third to one-fourth of the metal in the ore attends the operations of the most skilful metallurgist.

Antimony.—This metal was first obtained in the metallic state about the end of the fifteenth century, since which period it has continued a useful metal for alloying with others in the production of soft-metal goods, and in medicine. England contains small quantities of antimony ore, principally alloyed with other substances; the continental mines also yield small quantities; but the principal supply of late years has been derived from the Island of Borneo.

Tin.—This metal appears to have been known from the earliest period of history: the mention of brass in Genesis, leads to the inference that the more fusible ingredient of this alloy was well known to the ancients. At first the trade in this metal was in the hands of the eastern nations; though the existence of productive mines in the east, other than those in the Malayan peninsula, is not known to modern Orientals. The Phœnicians traded to Spain for this metal, and subsequently to Cornwall. In the latter country the traditionary accounts handed down are found strictly in accordance with the discoveries of modern antiquarians, which seem to leave no room for doubting that a commerce in this metal from Britain to the East was carried on at a very remote period.

The tin mines of the Malayan peninsula have yielded large quantities, and bear evidence of great antiquity. Early in the last century the occurrence of rich deposits in the Island of Banca, in the adjoining archipelago, was made known. For several years this island yielded large quantities of tin with such facility, that British mines became depressed in consequence. At the present time, however, the yield of Banca has greatly diminished, and the major part of the tin of commerce is derived from Cornwall. Spain, Saxony, France, Chili, Australia, and a few other localities, produce very inconsiderable quantities.

The earliest Cornish mines were merely superficial excavations in the beds of ancient rivers and creeks, containing tin-bearing gravel and sand. Simple washing apparatus constituted nearly the sole appliances employed. With the exhaustion of the tin streams, attention was paid to tin-bearing rocks, which required machinery for their pulverization. This was supplied by the stamping-mill. At what date mills of this description were applied to tin-dressing is not certain. From their first application, however, they have continued to be the most efficient instruments devised for this purpose.

CHAPTER VIII.

IRON ORES AND THEIR CONVERSION.

Iron.—Iron is the most abundant and universally disseminated of the useful metals. It exists to a less or greater extent in a majority of the rocks of the globe with which we are acquainted; and enters largely into the composition of soils, imparting to them peculiarly valuable properties. From soils it is absorbed by vegetable structures of every description; it exists in the sea-water, and in springs generally; and it is found as one of the constituents of the human system. The quantity of iron thus distributed through nature is beyond all calculation.

Iron has rarely been found in a native state. The nearest approach to this state is exhibited by masses of meteoric origin, in which the per-centage of iron varies from 85 to 90; the remainder being composed principally of nickel and cobalt. It is stated that a lamina of native iron was found at Canaan in Connecticut, U.S., attached to a mass of mica-slate rock; and also in Europe, but only in small quantities, too small to be of any value. So great is the affinity of iron for other substances, that absolutely pure iron can only be obtained by the chemist in small quantities and with great difficulty by reducing pure oxide of iron in a glass tube, by means of hydrogen or by the galvano-plastic process.

The purest iron of commerce contains minute quantities of other substances; in fact, pure iron would not serve the uses to which iron is commonly applied. The purest iron presents a white silvery fracture, of an agreeable, soft, and brilliant lustre; it assumes a high polish when rubbed with a highly polished substance, but is easily tarnished, has a great affinity for oxygen, and is rapidly dissolved in acids. Alkalies, in every form, protect it from corrosion. The specific gravity of iron is 7·78; it is the most tenacious of all the metals; very soft in its purest state, but becoming extremely hard when alloyed with other metals, or with substances which combine chemically with it. It is singularly affected by magnetic currents, imparts a disagreeable taste when applied to the tongue, and emits an offensive smell when strongly rubbed.

The best varieties of bar-iron exhibit a slightly bluish tinge, and a porous fracture, and are rapidly oxidized by exposure to the atmosphere.

For manufacturing purposes the supply of iron is derived from the most prevalent of its ores. Those minerals which contain at least twenty per cent. of metal are usually considered ores; if they contain less, they are denominated fluxes. The ores of iron are found in nearly every large district, either as beds in the sedimentary rocks, or as veins and massive deposits in the older rocks; in which position the most valuable ores are obtained. Occa-

sionally the deposits are immense, partaking of the character of mountains, as in the case of the Gellivara Mountain in Sweden, the Iron Mountain of Missouri, and the Island of Elba: from the latter source ores have been worked from time immemorial.

Classification of Ores.—Iron ores have been variously arranged by different writers. The varied composition of the ores; their different degrees of richness; their geological position, and the comparative facility, or otherwise, with which they were converted into crude cast-iron, have severally furnished data for their classification into separate systems. Inasmuch as the study of geology now forms part of the course of instruction in elementary science, and its principles are pretty generally understood; it is thought that a geological classification of the ores will be the simplest and most useful arrangement for the student and general reader. In pursuance of this plan, the ferruginous products of the several formations will be described in a descending series.

Iron Ores of the Alluvian and Diluvian Periods.

In the superficial accumulations of decomposed vegetable and animal matter composing soils, in deposits of sand, gravel, and clay, formed by the action of water, iron exists in varying proportions up to six per cent. by weight of the mass. There has not been discovered in this system any concentration of the ferruginous matter into beds or other deposits of a richness superior to that of the adjacent mass. Boulders of the older rocks, moved by the action of water and ice drift, are frequently found to yield a higher per-centage of iron, though possessing no commercial value. In the North American and some other states, magnetic iron-sand frequently accompanies the drift at the foot of mountain ranges. Bog-iron ores, also, in small quantities, very frequently accompany accumulation of drift under similar circumstances.

The Tertiary Formation.

These geological strata are characterized by a similar barrenness of iron ores. The crag, fresh-water, and marine beds, consisting of gravel, marls, clays, impure limestones, &c., contain a small admixture of iron; but present no indications of rich deposits of the metal. In the United States extensive deposits of hæmatite have been referred to the tertiary formation; a more critical examination, however, points to much older formations as their correct location.

Secondary Formation.

In this formation the most abundant deposits of iron ore are found to exist. Descending to the chalk system, the beds of ferruginous sands, with which this system abounds, are found covering a large area. They form the uppermost deposits of iron ore; but owing to their comparatively low yield of iron, have never been extensively wrought.

The Wealden Group.

This formation contains numerous beds of ore, similar in their general character to those pervading the lower chalk measures, but superior in the yield of iron. In England the ores of this system, as developed in the south and south-western counties, principally supplied the formerly extensive range of works which were carried on in Hampshire and Sussex, so long as the adjacent forests afforded the requisite fuel for smelting. The ores of this formation formerly quarried near Devizes, in Wiltshire, appear to have been of a comparatively rich description, and were in much demand for smelting. In the Isle of Wight, in Lincolnshire, and the wolds of Yorkshire, this formation, and its attendant beds of ore, cover an extensive area of ground. On the Continent the ores of this group and of the green-sand formation are worked to a considerable extent; especially in France.

As a class, the ores of this formation yield a low per-centage of iron, and at the present day are nearly neglected. Situated at a distance from any known range of coal-fields, their use at existing works involves an expensive transit; this, combined with their general leanness, acts as an effectual barrier to their extensive use. The average of a number of specimens from Hampshire gave twenty-six as the per-centage of iron contained in these ores.

Below the Wealden group are found those beds of oolitic iron-ore which have of late been extensively worked in Northamptonshire, and the Cleveland district of North Yorkshire. Occurring in beds of considerable thickness (ranging from a few inches to twenty feet and upwards), and frequently containing a large per-centage of iron, these ores, though very similar in their chemical character to the ores of the Wealden group, have rapidly attained to commercial importance

The composition of the ores in the Cleveland district is displayed in the accompanying analysis from the Memoirs of the Geological Survey :—

Protoxide of iron	39·92
Peroxide	3·63
Protoxide of manganese	·95
Alumina	7·96
Lime	7·44
Magnesia	3·82
Potash	·27
Carbonic acid	22·85
Phosphoric acid	1·86
Silica	8·62
Bisulphide of iron	·11
Water in combination	2·97
Organic matter and sulphuric acid	traces
Titanic acid	·03
	100·41

The extent of this description of ore is not yet accurately defined. It has been found in several places in Northamptonshire, Lincolnshire, and southwards in Oxfordshire, Rutland and Dorset, northwards into Yorkshire; and probably it will eventually be found in other localities, including the great chalk formation.

In the Northampton ores a greater degree of irregularity in the yield of iron is observed in the following analyses of a very rich and a very poor ore:—

Peroxide of iron	72·17	39·03
Silica	9·67	22·64
Alumina	2·35	5·92
Lime	1·11	7·53
Phosphoric acid	1·32	1·74
Peroxide of manganese	traces	1·60
Magnesia	1·24	3·27
Loss by ignition	13·51	17·60
	101·30	99·13

The ores of this formation are largely developed in France, and the cheap rates at which they are mixed and cleaned have greatly contributed to the late extension of the iron industry of that country.

The Lias Formation.

The lias formation appears to be very deficient in iron ores. A few thin beds of earthy carbonates are known to exist, and have been partly worked in Lincolnshire and Yorkshire; but the existence of any continuous beds, containing a rich per-centage of iron, has not been made known.

In the marls constituting the upper series of the new red sandstone, magnetic iron-sand is found. The red sandstones and magnesian limestones contain nodules of hæmatitic concretions; iron pyrites, too, are common. With these exceptions, however, this system is destitute of iron ores.

Carboniferous System.

The iron-works of this country derive their principal supply from the earthy carbonates of the coal measures, which furnish, with proper treatment, crude iron of the best quality. The great coal-fields of South Wales, Staffordshire, Yorkshire, and Scotland, and the minor fields of Shropshire, North Wales, and Warwickshire, are abundantly supplied with these carbonates. The principal range of the carboniferous or mountain limestone, according to Mr. Warrington Smyth's recent report, emerges from beneath the Durham and Northumberland coal measures on the east; is bounded by a steep declivity, overlooking the river Eden on the west; reaches its culminating point on the long mountainous ridge of Cross Fell, thus forming the vast tract of moorland near Alston, and in the high desolate region adjoining the Scottish border. The mode of occurrence is in bands and nodules of a dark bluish-gray colour, dispersed through the shale. The bands vary greatly in thickness, from a quarter of an inch to two

feet and upwards. The composition of the ores found in the Scotch field is well represented by the following analysis :—

Protoxide of iron	45·84
Carbonic acid	33·63
Protoxide of manganese	·20
Silica	7·83
Alumina	2·53
Magnesia	5·90
Lime	1·90
Carbonaceous matter	1·86
Moisture	·99
	100·68

Earthy carbonates from the other coal-fields are of a very similar character. The analysis of a specimen from the Warwickshire field is subjoined :—

Carbonates of iron	79·19
„ manganese	1·45
„ lime	5·85
„ magnesia	6·30
Alumina	·50
Silica	4·85
Phosphoric acid	·71
Water, bituminous matter, &c.	1·15
	100·00

The coal-fields of the Continent appear to be less abundantly supplied with these ores, and the quantity found is exceedingly limited. In France the coal-fields of the Garde and the Loire yield small quantities to the adjacent works. The analysis of a specimen from the latter field shows a considerable difference in composition from the Scotch and Warwickshire ores; the per-centage of phosphoric acid seems excessive, while that of carbonate of iron is very low.

Carbonate of iron	56·80
„ manganese	1·50
„ magnesia	6·30
„ lime	2·50
Phosphoric acid	6·10
Lime	6·60
Sand and clay	20 20
	100·00

The Westphalian coal-fields contain numerous bands of earthy carbonates,

and probably at no distant day they will be used in conjunction with the mineral fuel with which they are surrounded. Limited quantities also are believed to exist in the Biscayan provinces of Spain.

The North American fields contain workable bands of these ores, which, though inferior in richness to similar ores in England, are used to a considerable extent in competition with the hæmatites from the older formation. Virginia, Kentucky, Tennessee, Alabama, Pennsylvania, and Ohio, possess large deposits in their coal formations; while Missouri and the other less perfectly explored states of the west are believed to contain equally important deposits. By analysis, one of the best specimens of the Pennsylvanian field gave :—

Protoxide of iron	53·03
Carbonic acid	35·17
Lime	3·33
Magnesia	1·77
Silica	1·40
Alumina	·63
Peroxide of iron	·23
Bituminous matter	3·03
Water	1·41
	100·00

When oxidized, this ore forms hydrated oxides—brown or yellow hæmatites. In its original form, in the United States, it is found in round or flattened lumps, or spheroids, ranging from globules the size of a pea to masses of several tons weight, imbedded in clay, clay-slate, sandstone, shell, or limestone, and arranged in regular veins; but as there are often large masses of lead-slate between the balls, it is an expensive ore to work. The order contains about thirty-three per cent. of metal; when roasted, it emits the peculiar earthy odour incident to clay and clay ores.

The Carbonaceous Ores of the Coal Formations.

These occur extensively in some districts, but on the whole are much less abundant than the earthy carbonates. The coal-fields of Scotland contain the richest deposits hitherto discovered. North Staffordshire possesses valuable deposits, which are wrought to a large extent for the supply of local furnaces and transportation to South Staffordshire. South Wales also contains numerous seams of this ore, which are partially wrought in several places. Of late years, small quantities have been wrought in Ireland, and shipped to the Scotch works; but the extent of the deposits in that country is not yet ascertained.

The composition of a specimen of the Scotch carbonaceous ore (black band) is seen in the following results of an analysis by Dr. Colquhoun :—

Protoxide of iron	53·03
Carbonic acid	35·17
Lime	3·33
Magnesia	1·77
Silica	1·40
Alumina	·63
Peroxide of iron	·23
Bituminous matter	3·03
Moisture and loss	1·41
	100·00

The North Staffordshire ore has a similar composition, as is seen by the results of an analysis by M. Herepath. Generally, however, these ores contain notable quantities of phosphoric acid, and not unfrequently an amount of sulphur, even larger than is here represented under bisulphide of iron:—

Protoxide of iron	42·25
Bisulphide of iron	3·53
Protoxide of manganese	7·48
Silica	2·20
Alumina	·50
Lime	4·09
Magnesia	2 60
Bituminous matter, water, carbonic acid, and loss	37·35
	100·00

The South Wales ores of this class are not generally rich. By analysis, a very clean specimen yielded: protoxide of iron, 43·92; protoxide of manganese, 4·80; alumina, ·56; silica, 1·80; lime, 2·60; water, carbonic acid, and loss, 47·24=100·00. Ores of this class also exist in the Westphalian fields, and to a limited extent in the French fields. They have also been discovered in the State of Maryland.

The proximity of the ore to the fuel required for its reduction, and to the limestone used as a flux in the smelting furnace, has conferred on the several coal-fields such immeasurable advantages in the economical production of superior metal, that it is probable they will long continue to be the principal seats of the manufacture; more especially as, added to these advantages, an abundance of the finest fire-clays and refractory sandstones, as well as building stone of good quality, is generally found. It is thus seen that the great coal formations of this country contain, in an eminent degree, every material required in the manufacture of iron. The highly ferruginous character of several coal-fields is well exemplified in the following abstract of a section of the South Wales basin at Merthyr Tydvil, with the yield per acre of iron by the several descriptions of strata:—

	Thickness in feet.	Yield of Iron per cent.	Quantity of Iron per acre.
Rocks	309	3	39,204 tons.
Shales	589	10	196,020 „
Cliffs	125	4	21,780 „
Fire-clays	90	6	26,136 „
Coals	100	—	—
Iron ore	22	32	30,492 „
Clod	51	5	13,068 „
			326,700 „

In addition to the earthy carbonates and carbonaceous ores, the coal-fields contain iron pyrites, which, though considered worthless, and productive of injury, even when used in the smallest quantity, may ultimately be found useful for the production of a species of crude cast-iron. This ore usually occurs in the coal as concretionary masses, but at other times it is found adhering to, and is disseminated amongst, the rocks of the lower measures. The composition of the masses from the coal seams is usually 48 parts of iron, with 52 of sulphur mixed with carbonaceous matter.

Carboniferous Formation.—The mountain limestone generally contains a small quantity of iron disseminated through its mass, as oxide or bisulphide. Particular coal-fields also possess large deposits of rich hæmatite ore, of a quality adapted for the production of superior iron. From the mines of Whitehaven in Cumberland, and Ulverstone in Lancashire, large quantities of ore are mined and despatched to the ironworks of South Wales and Staffordshire. Gloucestershire also produces a considerable amount, while Glamorganshire, Derbyshire, and Scotland severally produce limited quantities of rich ore from the limestone measures. The carboniferous limestone of Northumberland produces a quantity of the carbonate of iron, which has recently received some attention from neighbouring smelters.

To the west, on the northern shoulder of Crossfell, and to the east at Killhope and in Weardale, the outcrops of iron veins again present themselves. In the eastern part of this region the sparry ore makes its appearance abundantly. Here, as elsewhere in the neighbourhood of Stanhope Burn, in Weardale, the veins are particularly charged with this ore. Mr. Smyth gives the following analysis of a piece of this ore derived from the Rispey iron in Rookhope, remarking that the high character of the iron produced from similar ores on the Continent, more especially the steel-irons of Siegen, Styria, and Carinthia, render the introduction of this ore into the British iron manufacture a step of much importance :—

RESULTS OF ANALYSIS.

Protoxide of iron	49·47
Protoxide of manganese	2·42
Alumina	traces

Lime	3·47
Magnesia	3·15
Carbonic acid	37·71
Phosphoric acid	traces
Silica	1·20
Sulphuric acid	traces
Bisulphate of iron	0·08
Organic matter	traces
Insoluble matter	3·77
	101·27

Here, as elsewhere, brown peroxide is mingled with the sparry ore, and Mr. Smyth thinks the brown ore is due to the decomposition arising from atmospheric action.

The composition of the richest kinds of the Whitehaven hæmatite is seen in the following tabular result of an analysis :—

Peroxide of iron	95·16
Protoxide of manganese	·24
Silica	5·66
Alumina	·06
Lime	·07
Phosphoric acid, sulphuric acid, and bisulphide of iron	traces
	101·15

A rich specimen of the Somersetshire hæmatite, small quantities of which are smelted in the South Wales works, gave by Mr. Mitchell's analysis :— Peroxide of iron, 85·000; alumina, 6·250; silica, 3·304; lime, 1·087; magnesia, 1·458; oxide of manganese, 1·601; sulphur, ·210; phosphoric acid, ·457; water, loss, &c., ·633 = 100·000.

It is worthy of remark that in fields deficient in the numerous thin bands of earthy carbonates, so characteristic of the Staffordshire, Shropshire, and South Wales districts; the absence of workable bands of ore interspersed between the seams of coal is amply compensated for by the immense deposits of rich hæmatite in the subjacent limestone. The Cumberland and Lancashire fields display this compensating principle in a high degree. The coal-bearing strata, though partaking of the same ferruginous character as in the other coal-fields, is nearly devoid of deposits of earthy carbonates. In the limestone formations, however, this apparent deficiency is met by a band of ore varying in thickness from a few feet up to twenty yards, which yields per acre a quantity of iron even larger than the aggregate of the thin earthy carbonates of the South Wales field. The small basin of Dean Forest is similarly situated in regard to supplies of ore; the rich deposits in and below the limestone, compensating for the barrenness of the coal strata. The South Wales basin, however, affords the most instructive example of the constant

occurrence of iron ore, in one form or other, in all our coal-fields. The northern portion of this basin is amply supplied with earthy carbonates, but is devoid of hæmatite in the limestone; the southern portion, on the other hand, is sparingly supplied with carbonates; but possesses considerable deposits of ore, in the limestone formation.

The Old Red Sandstone and Silurian Systems.

The quantity of iron disseminated through the old red sandstone is enormous, although the deposits of valuable ores appear confined to a few districts. This rock derives its colour from an admixture of peroxide of iron, of which it contains from 5 to 7 per cent. Calculating at this amount, the entire thickness of the system; it appears that the quantity of iron so dispersed, amounts to above one million tons per acre.

In the previous formations, the ore has existed as loose superficial accumulations, bands, or nodular concretions; in the old red sandstone and lower silurian rocks, iron ores are generally found as veins, more or less regular in their thickness and inclination from the vertical.

The ores found in these systems are of various descriptions and qualities. In the North American States they contain veins of fossiliferous ores and hæmatites, in conjunction with veins of limestone and shale, furnishing the largest supply to local iron-works. In this country, the principal workings are in Devonshire and Somersetshire. The latter county contains some veins of white carbonate, which are wrought to a limited extent; also very extensive deposits of hæmatite, which were worked for the supply of the charcoal furnaces of a former period. The yield of iron ore from Devon and Somerset is not large; but with greater facilities of transit to shipping ports, it is possible that these ores may become of importance to the Welsh iron-masters.

The general quality of the hæmatite of these systems may be gathered from the subjoined analysis of a specimen from the Exmoor Forest district. It must be borne in mind, however, that the average richness in iron of the larger deposits, is very much under the per-centage of this specimen.

Peroxide of iron	72·00
Silica	6·60
Peroxide of manganese	14·26
Alumina	2·10
Magnesia	·18
Phosphoric acid	·46
Water and loss	4·40
	100·00

Transition and Primary Formations.—The grauwacke and other older formations, are interspersed with iron ores of nearly every known description. Devon and Cornwall, where these formations are extensively developed, yield several valuable iron ores. The principal are the white carbonate, hæmatite, and hydrated peroxide. The white carbonate, when free from arsenical

iron pyrites, yields iron of a superior quality, though the average richness is below forty per cent. The quantity mined in England is very limited, and has no influence on the general quality of British iron. The Austrian iron-works in Styria and Carinthia use this ore, in conjunction with charcoal fuel, in the production of fine steel-irons, for which branch of industry it appears to be eminently adapted. It occurs also in other parts of Germany, in Russia, Spain, and other European states. Until recently, the explorations for this ore have been confined to Somersetshire, from which place a specimen of the following composition was obtained. From the Geological Survey already quoted, it will be seen that it is found in the Cleveland district. From Cornwall, also, a sample of considerable purity was obtained. The results of the Somerset and Cornwall analyses are annexed:—

	Somerset ore.	Cornish ore.
Protoxide of iron	37·33	51·53
Carbonic acid	35·80	34·50
Peroxide of iron	8·52	
Protoxide of manganese	12·65	11·41
Magnesia	4·52	
Moisture and loss	1·18	2·56
	100·00	100·00

The hæmatites of Cornwall and Devon are partially wrought for the supply of the Welsh iron-works; owing, however, to the absence of cheap transit, and a more careful supervision in cleaning, the quantity shipped is small in comparison with the magnitude of the veins. A sample of hæmatite from the eastern part of Cornwall yielded:—Peroxide of iron, 60,00; silica, 22·00; lime, 7·10; alumina, 7·20; magnesia 3·07; and oxide of manganese ·31 = 99·68. North Wales produces small quantities of hæmatite from the clay-slate formations of Caernarvonshire and Merionethshire.

In addition to the hæmatites with which these formations abound, the magnetic oxide is found in considerable quantity. Small deposits of this ore exist in Devon, and a few isolated fragments are obtained in Cornwall and other places; but if we except the recently-discovered beds of this ore in parts of Yorkshire, England is singularly deficient in the magnetic oxide. On the Continent, however, it is found extensively in Norway, Sweden, France, Germany, and other European States; Australia and New Zealand abound with it; the African continent contains large deposits; so also do the North-American States. In Turkey, Persia, and Syria it is manufactured into the celebrated Damascus blades; while in India it is used almost exclusively in the production of the wootz steel.

When pure, the magnetic oxide of iron is composed of one atom of the protoxide, with two atoms of the peroxide of iron; or, decimally, of iron 71·79, oxygen 28·21 = 100·00.

Other ores in which iron forms a conspicuous part, occur in the primary formations; one of the most common of these is the arsenical iron (mispickel), the average composition of which appears to be—arsenic 43, iron 36, sulphur

21 = 100. Iron pyrites (sulphuret of iron) is very commonly met with in conjunction with other ores; its composition is—iron 46, sulphur 54 = 100.

Chromate of iron (chrome iron ore) is rather a scarce mineral in England, but exists in small quantities in North America.

Franklinite is another mineral in which zinc forms 17 or 18 per cent. of the whole.

Titanite of iron, tungstate of iron, and some other forms in which this metal appears, occur so very seldom, that a detailed notice of them would be foreign to the plan of this work.

The Mining of Iron Ores.

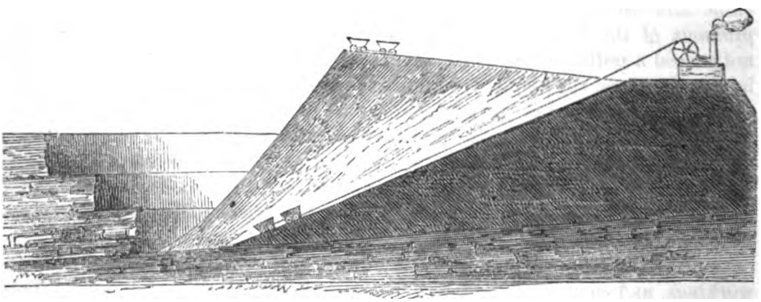
This branch of metallurgic industry is nowhere carried on to such an extent as in Great Britain. The amount annually extracted from the several geological formations exceed 12,000,000 tons—a quantity which, in regard to value and the capital invested, is second only to coal, amongst the mineral products of the kingdom. Half a-century ago, the total quantity raised did not exceed a million tons. This rapid augmentation in the rate of production has resulted from the frequent reduction in price, which has caused a proportionately increased demand for raw and manufactured iron; from the extensive use of the metal for our own railways and other structures in which it forms the principal material; and from the demand for Continental, American, and Indian railways. Consequent on this altered state of the trade, mining for iron ore has received an impulse, which improved modes and appliances have largely accelerated.

Formerly the ores were extracted from surface excavations or shallow workings, and carried on the backs of mules to the smelting-furnaces. This was the mode of conveyance largely practised in South Wales, in the early part of the present century. The mountainous character of this and other mineral districts precluded the adoption of canals, and necessitated the employment of this expensive and tedious mode of transport. Now, extensive systems of mineral railroads, inclined planes, and locomotive power, have placed such districts on a par with the most favoured, in respect to transit of minerals.

The mining of the ore is variously conducted. The simplest, and at one period the general, mode of extraction was by open excavations, the soil being removed to the depth of the ore, which is then removed also, and the cavity filled up with the rubbish. This is the mode practised in working much of the earthy carbonates of South Wales, Derbyshire, and other districts; although slight modifications are sometimes seen. In South Wales, wherever this system of open quarrying can be practised, it is carried out on an extensive scale,—occasionally over ten or twelve acres at once. Where practised on this large scale, the general arrangements are necessarily different from those adopted in smaller workings. The work is usually commenced at the outcrop of some known band of ore: at first the thin covering of earth is easily disposed of; but on following the band in depth, the increased burden of clays, shale, and stone, requires more engineering, in order to dispose of it in

an inexpensive manner. The difficulty is considerably increased where the proportion of ore to debris, as is generally the case, is very small; since the volume of the latter, in its loose state after removal, is fully double that of the space which it originally occupied. This increase of bulk is obviated in various ways: where an unlimited area of waste ground is available for its deposit, the surplus is removed thither; where, however, the disposable surface is limited to the area containing the ore, means are adopted for giving the heap of debris an elevation sufficient to contain the entire quantity produced.

When prosecuted to a considerable depth, thereby resulting in the working face attaining a height of 30 or 40 feet, the farther extension of the work is divided into two or three stages. The lowest part of the excavation is kept clear with the assistance of an inclined plane and small steam-hauling engine. This mode of "clearing the bottom," as it is technically termed, is illustrated



Plan of Subterranean Ore Workings.

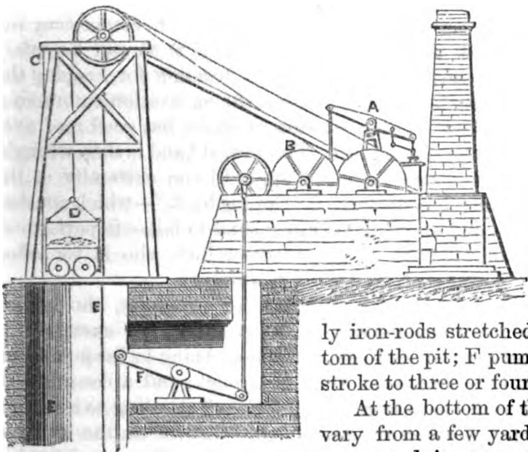
in the accompanying engraving. It will be seen, that, following the employment of steam-power, the elevation given to the accumulation is sufficient to embrace the entire produce within the horizontal surface exposed by the advancing workings.

In working with a shallow face, raw unskilled labour is usually employed; but where a deep face is wrought, the process is extremely hazardous, and a portion of the force employed requires to be that of skilled miners. The station of the latter is at the bottom, where they are employed in the dangerous occupation of undermining the superincumbent mass.

Extraction of the oolitic ores of Northamptonshire is conducted in a manner similar to quarrying common building-stone. From the great thickness of the beds of ore, and the comparatively thin covering of soil, there is little difficulty attending the disposal of the debris. A portion of the hæmatite of Cumberland is mined in a similar manner; and the occurrence of a mammoth vein of coarse hæmatite, in a cliff on the north coast of Cornwall, has been taken advantage of for an open working.

In parts of the South Wales mineral field, the descending band of ore is followed in its course by a dip-heading, or narrow gallery, from which the mass of material is brought up by a railway and steam-engine at top. At

stated distances apart on the inclined descent, levels are driven right and left, with cross-headings joining them, and a system of pillar and stall-working pursued in the extraction of the ore. The plan more commonly pursued, however, when the depth of covering has attained too great a thickness for removal, is to transfer the operations to a suitable point on the dip of the strata; a pit being sunk from the surface to intersect the bands of ore at the calculated depth. The pit thus sunk is generally large—seldom less than 16 by 8 feet; and if sunk through weak or shifting strata, it requires to be substantially lined with masonry or brickwork. A powerful steam-engine is employed for hauling up the rubbish; and where the ground is wet, a lift of pumps follows the sinking, in order to keep the pit properly drained. When completed to the required depth, it is fitted up with a pair of cages, which work between vertical guides fixed in the pit, for the purpose of supporting and steadying the train-waggons in their ascent and descent. These preparations are generally made on a scale adapted for the daily delivery of 400 or 500 tons of material. A sketch of the arrangements for winding and pumping is given in the accompanying figure, where A is the steam-engine; B winding and pumping-gear; C pit-head framing, made of balk timber; D cage and train-waggon; E E guides, commonly iron-rods stretched tight from top to bottom of the pit; F pumping-beam, making one stroke to three or four of the engine.



Winding and Pumping Gear.

At the bottom of the sinking, which may vary from a few yards to 150 fathoms, with an annual increase, levels are driven of a width, and height, sufficient for the passage of a horse and train of waggons. From the levels, headings are driven to the rise of the strata; and from off both sides of these headings, the ore is taken away by a series of excavations, alternating with broad pillars of solid ground, left as a support to the roof. The excavations will range about eight or ten yards wide; the same distance apart; and sixty or eighty yards long. During the operation of driving forward, the ore is taken away, filled into waggons, and sent up to the surface.

Where the work is performed entirely on the contract system, as is the case in nearly all the Welsh works,—the sinking the pit, driving the levels and headings, and other processes connected with the opening of the work, are undertaken at per yard deep or forward. This portion of the general

system of mining involves a large outlay of capital, and is technically known as "dead-work," from being almost entirely unproductive of mineral. The mining the ore, or "raising the mine," as it is generally termed, is undertaken at so much "*per ton*," as also are the labour and horse-hire in hauling; the wages of pitmen, and other operatives employed in the mine: hence the operations in the mine resolve themselves into those attending the "dead-work," and those appertaining to "raising the mine." In a well-regulated mine, the dead-work is prosecuted at a rate that ensures, at all times during the continuance of the workings, ample room in the headings for the miner to commence new excavations, as others are worked out.

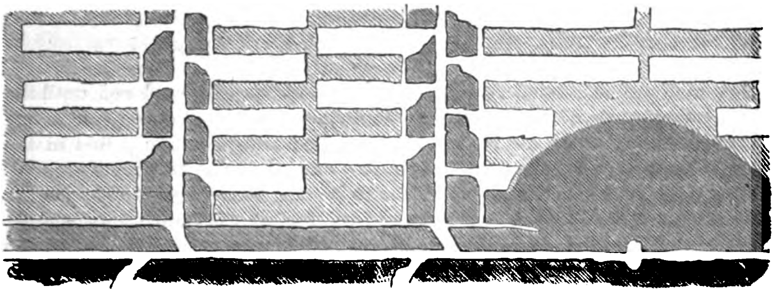
While driving the excavation, or, as it is technically called, "*stall*," the miner supports the roof in his immediate vicinity with stout wooden props; these are generally larch, or fir-poles, varying in diameter up to twelve inches; occasionally also with "*stows*," a moiety of the rubbish produced in the excavation in his rear, leaving only a sufficient roadway for delivering the waggons. If the roof be good—that is to say, not liable to fall—and if circumstances warrant such a course of action: the miner, on completing his stall, proceeds to draw back the pillar, or so much of it as can be safely wrought; leaving a small solid block adjoining the heading for keeping the latter open to the proper extent. When, however, the excavation embraces a second band of ore, with an intervening stratum of shale, but good roof over all, a somewhat different system is pursued. The lowest band is then wrought first, and the superincumbent mass propped up, until the extremity of the excavation is reached; when a process termed "ripping back,"—which consists in knocking out the props, and allowing the upper band to fall,—is performed. This is an operation of considerable danger to the miner, who is too often caught in his retreat by portions of the falling stratum.

When a mine is opened on strictly workmanlike principles, the bottom is left unworked, until the abandonment of the pit, with the exception of driving the necessary levels and air-ways, the object being to keep it in an efficient state until the area embraced by it is wrought out a considerable breadth around. This breadth of unworked ground is left standing as a support for the pit, and to prevent unnecessary strain being thrown on the adjacent levels. In cases where, from cupidity, or want of skill, such a provision has been omitted, the sinking of the strata, or the withdrawal of the ore, scarcely ever fails to crush the levels, and to seriously injure the pit.

The mode of mining ore "by pillar and stall" is exhibited in the following engraving. At first the stall is narrow; but as it recedes from the heading, it is widened: air-ways are driven, and ventilation forced, wherever the atmosphere seems stagnant. The dark shading shows the portions allowed to stand for the permanent support of the roof, while the lightly-shaded portions represent the parts drawn away after completing the stalls.

The mining of hæmatite in Cumberland, Dean Forest, and Cornwall, is conducted on similar principles, modified to a slight extent. The nearly perpendicular direction of the veins, necessitates, in nearly every instance, the sinking of pits. These are commonly of a smaller size; and instead of

the lining of walled masonry, they are strengthened by a series of timber frames and linings. The shafts are vertical; and the oblique manner in which the sinking cuts the line of stratification, throws a great crushing strain on



Plan of Subterranean Ore Workings.

these frames, which not unfrequently collapse, and prevent a further prosecution of the mine. At the depth fixed on, a short cross-cut is driven to meet the vein and horizontal levels extended right and left into the mass of ore. This usually occurs with a degree of regularity in the thickness; but in the Dean Forest district, large deposits are occasionally met with, after intervals of unproductive ground. In mines in which the veins possess a considerable underlie, or deviation from the perpendicular, the roof is temporarily kept up by heavy timbering, which eventually collapse, and render such portions of the mine inaccessible.

Cleaning Iron Ores.

On reaching the surface, the earthy carbonates of iron of the coal formations is transferred to heaps, and exposed to the disintegrating influence of the atmosphere for several months. The effect is seen by the separation, in a loose and friable state, of the adhering clay shale, leaving the ore clean and fit for the furnace-yard. This simple and apparently inexpensive mode of cleaning the ore is singularly effective; it is, however, so far objectionable that it necessitates the maintenance of six or eight months' stock of ore on hand, which, even in small works, absorbs a large capital. No other system has yet been devised, though it is probable that research will eventually discover one not open to this objection.

The oolitic ores of France, and the magnetic oxides and rich hæmatites used in other places, also undergo a cleansing process before admission to the furnace. With the greater number, advantage is taken of the superior specific gravity of the ore to effect the removal of the extraneous matter. A few of the magnetic iron-sands are cleaned in a manner very similar to that pursued in the winnowing of corn. The hæmatites, and ores of the primary formations of England, undergo no other preparation than a partial hand-picking, to separate the largest masses of refuse matter.

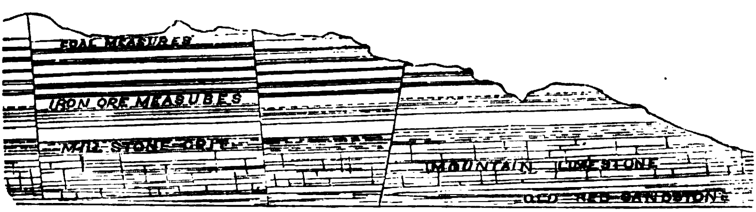
CHAPTER IX.

FUEL USED IN THE MANUFACTURE OF IRON.

Dry and charred wood constituted the fuel universally employed until the last century, when the high prices consequent on the growing scarcity of wood, led smelters to use for smelting purposes charred mineral fuel in the high-blast furnaces. The success which followed its use in this department, eventually led to its employment in refining the crude iron and in forging it into bars. At the present day mineral fuel is used almost exclusively in the home manufacture: the small quantity of charcoal consumed in the manufacture of nail-rod, and iron-plate for subsequent thinning, gradually diminishes; while the quantity used in smelting, is limited to that required for the annual production of a few hundred tons in the Ulverstone district. Imitating the example set by British manufacturers, mineral fuel has been applied to smelting and bar-iron making in France, Belgium, Germany, Spain, and the United States of America; nevertheless, in some of these countries, especially America, the comparative cheapness of wood compared with that of mineral fuel, is seen in the larger number of the works still using charred wood. Belgium manufacturers employ mineral fuel almost exclusively; Sweden, Norway, Russia, Austria, and Italy, smelt charcoal-iron only; and the same may be said of Oriental and African manufacturers.

The bands of coal in our coal-fields are numerous, but at present it is only the best and thickest that are worked. Bands less than two feet are not wrought, unless in conjunction with other minerals, as ore and fire-clay. With the exhaustion of the fields, attention will doubtless be directed to these, and economical methods of extraction devised. Thick bands of carbonaceous matter, capable of yielding large quantities of heat during combustion, will also receive attention, and be applied to useful purposes.

The manner in which the ore, fuel, and flux generally occur in the larger coal-fields of this country, is well exemplified by a sectional sketch of a portion



Section of part of the South Wales Mineral Basin.

of the northern outcrop of the South Wales field. In the accompanying engraving a considerable thickness of millstone grit, shale, impure coal, and ores,

intervene between the iron-ore measures, and the great deposit of mountain limestone; but the gentle inclination of the strata in this region (the fall being about 1 in 12 horizontal), aided by the hilly character of the country, causes the lowest stratum of limestone to appear at the surface, within a mile or two of the appearance of the main deposits of ore and fuel.

Coal-mining is prosecuted in a manner very similar to the extraction of the iron ores of the same district. In South Wales a considerable quantity is derived from open workings, or quarries, and in a few other localities limited quantities are thus obtained. It is, however, from deep subterranean excavations that the chief amount of mineral fuel of this country is derived. The method of sinking the pits, the adaptation of steam-engines, the apparatus for pumping and winding the cages, guides, and waggons, have been already described; the operations of driving the levels and headings, and the opening of the oblong excavations called, in the Welsh districts, *stalls*, is conducted in nearly the same manner, whether the mineral sought be iron-ore or coal. In the South Staffordshire, and other districts, the system pursued in the opening of the work at bottom is slightly different, the result of peculiarities in the several fields as well as local customs; but it may be remarked, that extraction without breaking, and at the cheapest rate, is the object which determines the process to be followed in working the several bands.

Several of the coals yield large quantities of inflammable gas, to dilute or dissipate which special ventilating powers are required. The iron-ore miner is seldom incommoded by impure air; and a small ventilative apparatus suffices for an extensive area.

Coking Coal, and Coke Manufacture.

Mineral fuel is composed essentially of gaseous and solid substances in varying proportions. In the best and purest specimens, the portion capable of forming gaseous compounds with oxygen, or of existing naturally as a gas, forms 98 or 99 per cent. of the weight; other specimens yield 9 or 10 per cent. of solid earthy substances, which remain as ashes. A few contain 18 and 20 per cent. of ashes; but such varieties are not extensively mined, and at present only possess value in the absence of others containing a greater proportion of gases. The ashes of coals vary in the elements; their relative proportions in different districts being influenced in a degree by the character of the surrounding strata. The gaseous constituents of coal, so far as analysis has determined, are uniform in number, but vary greatly in their relative proportions.

Common pit-coal contains, as constituents capable of entering into gaseous combination, carbon, hydrogen, oxygen, nitrogen, and sulphur. Carbon forms the principal ingredient in the combustible value of coal. The purest anthracite of South Wales and Pennsylvania contain 92 or 93 per cent. Other coals of a weak bituminous character, such as the Dean Forest and Somersetshire, yield 60 or 65 per cent.; between these two extremes are found the coals known as cubical, reedy, caking, clod, cherry, splint, and cannel—names too often used indiscriminately, without reference to chemical

composition, or other sufficiently distinguishing peculiarity. The hydrogen, nitrogen, and oxygen, occur in varying proportions—the former in some coals to 5 or 6 per cent.; nitrogen 2; and oxygen up to 18 or 20 per cent.

Sulphur is a constituent to the extent of 3 per cent. in some coals, but the larger number contain from 1 to 1½ per cent., while a very few yield less. The presence of this substance is prejudicial to the use of the coal in smelting and refining; and when existing in the larger proportion, renders it altogether unsuitable for the production of the finer kinds of iron.

The ashes of coal consist frequently of silica, alumina, and oxide of iron, with minor quantities of lime, magnesia, manganese, potash, phosphoric acid, and sulphur. The three first commonly constitute 70 to 80 per cent. of the whole; their presence exercises no injurious effect on the quality of the metal: the two last enter to the amount of 1 to 7 per cent., and to this extent they are injurious. Compared, however, with the sulphur of the fuel, and phosphoric acid of the ores, the ashes contain only a very minute quantity of deteriorating mixture, the effects of which may be safely neglected in practice.

For smelting purposes, the amount of sulphur and ashes being similar, the value of a coal will be nearly proportional to the amount of carbon. For the blast and refining furnaces, coke was formerly the only state in which coal admitted of being turned to account; and even now it is probable that more than half the total quantity of British manufactured iron is so prepared. The coking of coal is analogous to the charring of wood, and is conducted in a similar manner, either on the open ground, or in close vessels. An essential condition in forming coke is, that the coal swells on being heated, and changes into irregular, spongy masses, which adhere intimately together; thus producing a material free from sulphur and hydrogen, and which is not altered by heat.

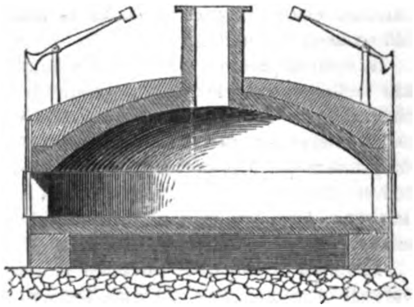
Coking in the open air is commenced by levelling a dry sandy surface of twenty or thirty yards diameter, and building in a rough manner in the centre a dwarf brick chimney, with apertures and open joints at the bottom; around this a stratum of large coals is loosely placed, and on these, other coals, till a circular mound, thirty to thirty-five feet diameter, and of the height of the central chimney, is formed. When coal abounds in sulphur, however, as well as bitumen and water, the best mode of coking is in rows, or clamps; the length of such rows may be from twenty to a hundred feet, but in width they must not exceed twelve. Fire is applied to these masses, and a partial combustion maintained by the indraught of the chimney. When the entire mass is ignited, the lower portions are covered with a thick stratum of dust from other cokings, which operation is continued to the centre; thus cutting off the further admission of air, and concentrating the heat already yielded to the expulsion of the volatile gases. The process of covering is continued, any broken part being immediately repaired, until the mass has cooled down, when it is opened, and the coke, now cohering in a mass, dug out, and wheeled to the smelting furnaces.

It may be observed that coke is an exceedingly hygroscopic substance,

absorbing water to the amount of 50 to 60 per cent. increase of weight in a single night: it should therefore be carefully protected from the weather, otherwise the iron fused with it will be much deteriorated.

The yield of coke from a given weight of coal appears to be mainly dependent, when the process has been well conducted, on the original quantity of carbon; the richest give 88 to 90, and the poorest coals 40 to 45 per cent. of coke.

The use of close vessels in coking has largely increased of late years. They may be divided into two classes—brick furnaces or ovens; and hermetically sealed retorts. Brick ovens are variously constructed—circular, oval, square, and rectangular on the plan, with arched or domed roof, and with or without machinery for discharging. The circular form, of which a section is given in the accompanying engraving, is used to a considerable extent in coking small coals of a bituminous character. The interior chamber is lined throughout with firebrick, and strongly bound with iron hoops on the outside to resist the thrust of the roof. A short chimney, sometimes carrying a damper, rises from the centre of the dome; communicating with the interior are two doors, two feet square, through which the coals are charged and discharged.



Section of Coke Oven.

The process is conducted by lighting a fire on the floor of the oven, and charging into it three or four tons of coals, or until about three-fifths full, allowing a free admission of air till the whole is in an incandescent state. This is accelerated by the draught of the chimney. When the interior is at a full red heat, the further admission of air is prevented by sealing up the doors. It is now left a few hours, occasionally inspected through a small hole in the door, until the falling off in the escape of gas from the chimney indicates the completion of the process. The doors are now opened, and the red-hot coke drawn by bars and hooks on to the floor of the coke-yard. In recommencing the process, the heat communicated to the brick-work by the partial combustion of the previous charge materially assists in the rapid disengagement of gas, and renders the lighting of a second fire unnecessary.

Probably the most objectionable part of the coking in ovens is seen in the universal use or abuse of water in cooling the resulting red-hot coke. The entire process occupies only twenty or twenty-four hours, and immediately a charge is drawn it is required to be removed out of the way of operations. Water is applied in torrents, saturating the coke, and entailing evils of the first magnitude in the economical working of the smelting-furnace. Coke thus cooled frequently contains 30 to 35 per cent. of water.

Coking in retorts, as pursued in the manufacture of gas for lighting purposes, is a species of distillation in which the heat required for volatilizing the lighter gases, is derived from fuel burnt outside the retort. The expulsion of the gases, and production of a sound coke, absorbs a quantity of heat, in whatever way the coking may be performed. With the majority of coals, the gases thus expelled have a calorific value greater than the heat expended in their separation. The distillation in close retorts is invariably done with a view to the utilization of the gases evolved; and the process is prosecuted so long as the coal yields gas, without reference to the quality or quantity of the resulting coke. Hence gas-coke is held to be of inferior quality, and is seldom used in smelting.

In open-air coking, a partial combustion of the fuel is permitted to generate sufficient caloric for the requirements of the process; if successfully performed, the quantity thus consumed will not be greatly in excess of the heat rendered latent. The use of ovens is attended with a diminished consumption, inasmuch as the brick-work reduces the amount of radiation to the surrounding atmosphere, and acts as a store of heat from one charge to another. An advantage of this kind, however, may be more than counterbalanced through inattention to other points.

The bulk of the coke obtained is larger than that of the coal used; the increase of volume varying with the amount of volatile constituents, and the mode in which the operation is conducted. Coals containing much hydrogen and oxygen, expand considerably; while those having the largest quantity of carbon undergo but a small increase. If coals of the former class be placed in a red-hot vessel, and the operation prosecuted at a bright red heat, the resulting coke occupies a space twice as great as that of the original coal. This bulky coke, however, contains 10 to 20 per cent. less carbon than it would have contained if coked slowly at the lowest heat compatible with perfect carbonization.

Wood-charring is conducted in a manner similar to that pursued with open coking of mineral fuel. The short billets or logs of wood are placed in an inclined direction around a centre post to form a circular heap, which is covered with chips, leaves, and a thick coating of breeze from former charrings. Fire is applied to the heap, and a smothered combustion maintained until the whole has ignited, when further access of air is prevented by additional coverings of dust, and the pile is allowed to cool. At other times, the wood is piled in longitudinal heaps, one end of which is covered and fired, while the other is being extended by the addition of fresh logs. In this manner the process may be seen in continuous operation; the setting, firing, and drawing going on simultaneously.

Hard wood logs, twelve months cut, yielded fifty-five per cent. of woody fibre, after having been dried at 400° F. Charred in a close vessel without entrance of air, the coal produced gave twenty to twenty-five per cent. of the original weight of the wood. With pine and other soft woods, the yield of coal varies from ten to eighteen per cent. Oak, beech, mahogany, lignumvitæ, and hard woods generally, yield the best coals for smelting.

A quantity of charred wood is obtained in the distillation of pyroligneous acid. The green wood is placed in iron retorts and submitted to a high temperature for twenty-four hours, when the carbonization of the wood is complete. A charge of beech yields forty-five per cent. of wood vinegar, eight per cent. of combustible oil, and twenty-two of charcoal, showing a loss of twenty-five per cent., probably due to moisture. The soil on which the timber grew appears to affect the quality and quantity of the products, equally with the kind of wood employed. Timber grown slowly on a dry soil yields the largest quantity of liquid products, as well as a maximum of charcoal. For smelting purposes, however, wood-charcoal prepared in this manner is held to be greatly inferior to that prepared in open mounds.

Fluxes used in the Smelting Furnace.

The iron ores smelted in England contain, for the most part, considerable quantities of silicious and aluminous earths, and require the addition of a thin substance to form a readily fusible compound, incapable at high temperatures of holding any considerable quantity of iron in solution. Limestone forms the cheapest material, and is used for the purpose whenever attainable. The mountain limestone of the carboniferous era is preferable to others: immense beds of it are composed of nearly pure carbonate of lime. At its northern outcrop, the South Wales deposit frequently contains ninety-eight per cent. of carbonate of lime, with very small quantities of silica, carbonate of magnesia, sulphate of lime, and oxide of iron.

Chalk forms an excellent flux: and where obtainable in sufficient quantity at a cheap rate, is sometimes used instead of limestone. It may be designated as a friable carbonate of lime, mixed with a very small amount of silica and oxide of iron.

Oyster-shells have been recommended by one author, as a suitable flux in smelting furnaces. Containing a large per-centage of phosphate of lime, as well as water in the state of an hydrate, they form about the worst material which it is possible to adopt. The water may be expelled at a high heat, but the phosphate remains, to the injury of the iron.

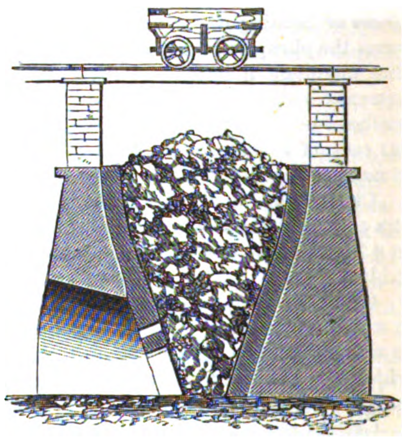
Calcination of the limestone is frequently performed previous to introducing it into the furnace, with a decided advantage in the quality of the product and yield of fuel. To analyse the advantage, however, is a matter of some difficulty. Caustic lime is a very hygroscopic substance; it absorbs moisture from the atmosphere with great rapidity, and passes into an hydrate in a few hours. Hence it is absolutely necessary to keep it perfectly dry, and to remove it from the calcining kiln only as required for filling into the blast furnace.

CHAPTER X.

THE CALCINATION AND SMELTING OF IRON ORES.

CALCINATION of iron ore is performed either in kilns or in the open air. The earthy carbonates of the coal-measures, and the carbonates of the primary formations, are usually submitted to this preliminary operation. Some smelters calcine the ores of the oolitic formation, but the hæmatites and magnetic oxides are rarely subjected to the process. In South Wales, kilns are usually employed; the Staffordshire, Shropshire, and Scotch smelters follow the open-air plan, and calcine the ore in large heaps.

The calcining kiln is usually built in the rear of the blast furnace, into which the prepared ore is wheeled after weighing. Its general form and size are held to be of little moment, so long as the thorough calcination of the ore is effected economically. The general form is that of an inverted frustrum of a cone; the major diameter 8 or 9 feet, and the height 14 or 15 feet, width at bottom 2 feet. Communicating with the interior at bottom, is an aperture for the withdrawal of the calcined ore; also a few small orifices for the admission of air. At a height of 5 or 6 feet above the top of the kiln, a railroad is supported on pillars, over which the loaded tram-waggons pass and deliver their contents into the cavity of the kiln. These arrangements are best seen by the accompanying section of a calcining kiln.



Section of Calcining Kiln.

In commencing operations with a new kiln, a fire is lighted on the floor, and when in full ignition is covered with a quantity of ore. Other fuel is now added along with successive strata of the ore, until the interior is filled with ignited fuel and ore. Active combustion is maintained at top, where the ore is subjected to a high temperature, gradually decreasing in its descent to the discharging aperture. If the operation be continuous, as is generally the case, the kiln requires to be filled regularly and evenly over its entire area, with due attention to the stratification of the ore and fuel. If the fuel be thrown on irregularly, a portion of the ore is not thoroughly calcined; if thrown on in excess, not only is fuel wasted, but the calcining power of the kiln is diminished.

It is necessary also that there should be considerable uniformity in the dimensions of the pieces, otherwise the resulting ore will be more or less imperfectly calcined. To ensure successful results, the operation demands unremitting attention throughout.

The process of calcination in the open air, as pursued in several districts, is rude, expensive, and incomplete. Ore is first thrown on a levelled space; next a quantity of fuel is added; then more ore and fuel alternately, until a large heap is formed. It is now ignited, and the whole allowed to burn until the fuel is consumed. The cooled mass is dug over, and the calcined ore wheeled to the blast-furnace; while such portions as are imperfectly done are placed aside for a second operation.

The perfect calcination of the ore results in the expulsion of its volatile constituents, and the conversion of protoxide into peroxide of iron, if protoxide exist in the original ore. The volatile substances comprise carbonic acid, water, sulphur, and organic matter. In the earthy carbonates, the carbonic acid forms about three-tenths of the weight of the ore; its complete expulsion, therefore, is deemed a matter of essential importance. The amount of water varies with the character of the ore: the hydrated hæmatites of the oolitic formations contain 12 to 16 per cent.; the hæmatites of Cumberland, Dean Forest, and Cornwall, 5 to 10; while the earthy carbonates of the coal-measures, range from 2 to 5 per cent. To expel the entire quantity of water chemically combined, as well as such as exists in the hygroscopic condition, the ore requires to be heated to a low redness. The amount of sulphur is generally small, and is only partially oxidized during the process. Carbonaceous ore, such as the (black band) ores of Scotland, also lose, by combustion, a large amount of coally matter. From these several causes the loss of weight by calcination is large—in some varieties amounting to nearly 50 per cent.

During calcination, the ore gradually loses its bluish-gray colour; at first it deepens, until a bluish-black is attained; the latter, in its turn, gradually disappears, and gives place to a reddish-brown.

If a large imperfectly calcined nodule from the coal-measures be broken, the outer portion displays the reddish-brown tint, gradually passing through a blackish colour into the original bluish-gray at the centre. In this central portion, yet unacted upon by the fire, the iron is in its original state of carbonate of the protoxide: the blackish portion contains the metal as the magnetic oxide, while the outer portion has been thoroughly peroxidized. The expulsion of the carbonic acid, and the oxidation of the ore to the state of magnetic oxide, is effected at a comparatively low temperature; but the further rapid oxidation of the ore to the condition of peroxide, appears to require a high temperature—one approaching that of the blast-furnace.

As a general rule, ores of the same formation are best calcined together, in preference to an admixture with ores from other formations. If a particular ore should contain much sulphuret, it ought to be treated by itself, lest the sulphurous acid produced should contaminate ores which are cleaner.

The separation of the sulphur, when existing as sulphuret or bi-sulphide of iron, may be greatly facilitated by introducing a jet of high-pressure steam

to the ore, along with a sufficiency of atmospheric air while at the highest temperature of the calcining furnace. The sulphur passes off as sulphuretted hydrogen, while the metal remains oxidized.

Reduction of the Ore to Metallic Iron.

This is conducted in two ways—first, by deoxidizing rich ores, at a sufficiently high temperature for the particles to cohere, so as to be incorporated into a bloom by repeated hammering—a mode universally followed at one period, and still practised by all semi-civilised nations; secondly, by deoxidizing the ores, and by fusion along with a flux, whereby the metal separates by its superior specific gravity, as in liquid cast-iron—a process followed by all nations manufacturing considerable quantities of iron.

It is not improbable that the smelting appliances of the ancient Briton were similar to those now used by some of the nations of Central Africa, as described in Park's travels. The native African builds a small furnace of clay, about three feet diameter, and nine feet high, wattled around to prevent its cracking to pieces during the blowing. At the bottom it is furnished with a number of small orifices, into which clay tuyere-pipes are firmly luted with the same material. These pipes are formed around a central core of wood, strengthened by strips of grass, and dried in the sun. The bellows, which are made of goatskin, appear to be used merely for commencing and diffusing the heat through the fuel, the furnace being afterwards urged by the great indraught of air through the clay tuyere-pipes. The filling of the furnace is conducted with commendable regularity: first a quantity of dry brushwood, then alternate layers of charcoal and broken ore up to the top, the charcoal being in excess. As the charge descends, further quantities of charcoal are added until the end of the third day, when the tuyere-pipes are withdrawn, and the air allowed free access to cool the furnace. When quite cold, part of the front of the furnace is removed, and the reduced metal which had accumulated at the bottom taken out.

The ore used in this primitive furnace appears to be a nearly pure peroxide of iron; from which circumstance, and the purity of the charcoal used, the resulting mass has little cinder adhering to it. Exposed also to the deoxidizing influence of numerous currents of air, it partakes of the character of steel, and requires repeated forgings to fashion it into articles of utility.

The Hottentots of Southern Africa manufacture small quantities of iron for fabrication into their rude instruments of warfare. Their furnace is of a conical form, built of a clay which becomes extremely hard and refractory after burning; an opening is left at the top, for the admission of the ore and fuel, and escape of the gases, and other openings occur at bottom for the insertion of the clay nozzle of the rude bellows, made of goatskin. These are worked by alternately distending and compressing them by the hand. The ore employed is a rich oxide, with which the furnace is supplied along with charcoal fuel, until a sufficient quantity of metal has accumulated. When the operation has ter-

minated, a lump of metal of a pasty consistence is extracted from the hearth, and converted to its purpose with immense labour.

The nations of India have for a very long period been in the habit of smelting cast-iron. Those resident in the southern part of the continent, use small furnaces about five feet high by two feet wide in their largest diameter. The material is well-tempered clay, which appears to withstand the action of the fire, equally well with the best English fire-clay. Bellows for supplying the blast, are made of a pair of goatskins, which deliver the air into a clay tuyere-pipe, the point of which projects considerably into the furnace. After undergoing a slight drying in the sun, the furnace is partially filled with charcoal and ignited at the bottom. The ore used is the magnetic oxide, combined with variable proportions of quartz, from which it is separated by pounding and washing; it is moistened with water, to prevent its too rapid descent amongst the interstices left by the charcoal, with which it is charged in regular rotation. The blast is directed into the furnace for a few hours, effecting the metallization of the ore with the combustion of the fuel; when the process is complete. A portion of the furnace is now taken down, and the cake of metal extracted. To separate any extraneous matter, it is beaten with mallets and cut into halves, the better to show its quality.

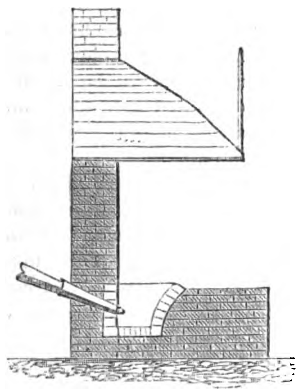
The natives of the Himalayan ranges smelt small quantities of ore in a modification of the preceding furnace. The height of the furnace, which is built of clay, is nearly the same as the southern furnace, but the diameter is only about one-half; it is supported over a fire-place upon a stone pedestal. The magnetic oxide of iron is mixed with charcoal and filled into the furnace, where it is reduced by the alternate action of two goatskin bellows, and eventually tapped through an orifice in the bottom.

The Persian method of smelting differs from both African and Indian. Rich ores, of the magnetic oxide and red hæmatite classes, are common in that country, where the manufacture was early established. The hearth, in which the reduction of the ore is effected, is about 15 inches square at bottom by 12 inches deep, and is partly excavated out of the clay floor of the hut in which the operation is performed. Into a clay tuyere-pipe, built in a low wall, which forms one side of the hearth, the nozzle of a pair of bellows, which constitute the blowing apparatus, is inserted. The smelting hearth is separated from a deeper and larger hearth, into which the cinder runs over a dam of powdered charcoal and cinder from previous workings. The hearth is covered with a chimney, passing through the roof of the hut. In smelting, the clean ore, of the size of hazel nuts, is filled into the smaller hearth, along with a due proportion of charcoal. The filling of the hearth is completed with a layer of charcoal, and the reduction proceeded with. After igniting the charcoal, the bellows are urged to the delivery of a stream of blast until one side of the enclosed ore is thoroughly deoxidized and softened into a pasty state, when it is turned round so as to expose the other portion to the blast, and the bellows finally urged to their utmost power. The blast is continued for about three hours, when the charge of ore will have been reduced to a

semi-fluid mass. At this stage the dam is taken down, and the mass of reduced iron in the hearth is detached from the sides and bottom. It is then lifted from the hearth on to the floor, where it is beaten with hammers to expel the cinder that may have lodged in the interstices of the bloom, preparatory to a more regular hammering on the anvil.

The ore—a mixture of the magnetic oxide and finest red hæmatite well-cleaned—contains nearly 70 per cent. of metal; but in the hearth the produce averages only 50 per cent. of finished blooms, with a consumption of 3 of charcoal to 1 of iron produced. The make of hearths of this size, amounts to about 100 lbs. daily, of a metal which is subsequently converted into steel of excellent quality.

The Catalan forge, an improved form of the Persian low-blast furnace, is common on the Continent, also in the States of North America. It consists of a low erection of stonework, about seven feet square, with a fire-place in one corner, surmounted with a flue and hood similar to old-fashioned smithy fires. The fire-place, or, more properly, hearth, is about two feet square at top, and a little more than half that depth, lined with refractory fire-stone, cemented with clay, and so arranged that damp may not ascend to the bottom stone. The blast is produced by a pair of ponderous wooden bellows, driven by a water-wheel, and delivering the air through a conical tuyere iron in the back. Reduction of the ore to a metallic state is effected nearly in the following manner:—The hearth being lined with charcoal-dust, and the charge of ore placed against and above the side farthest from the blast; the intervening space is filled with charcoal, which is heaped up against the tuyere wall to a height of two or three feet. At first a light stream of blast is directed upon the incandescent fuel; when it has been applied about two hours, a portion of the ore will have been reduced at the bottom, forming a pasty mass of semi-fluid iron; afterwards a stronger blast is employed, and the unreduced portions brought within its influence. In a short time the iron is completely reduced, and the cinders run off through a tapping-hole, leaving the mass of iron in the hearth. This is quickly lifted by iron bars to such a position before the blast, that the intense heat thrown on, agglutinates its particles into a bloom of ten or twelve inches diameter; it is then taken to the hammer, shingled, and eventually converted into hammered bars or into steel.

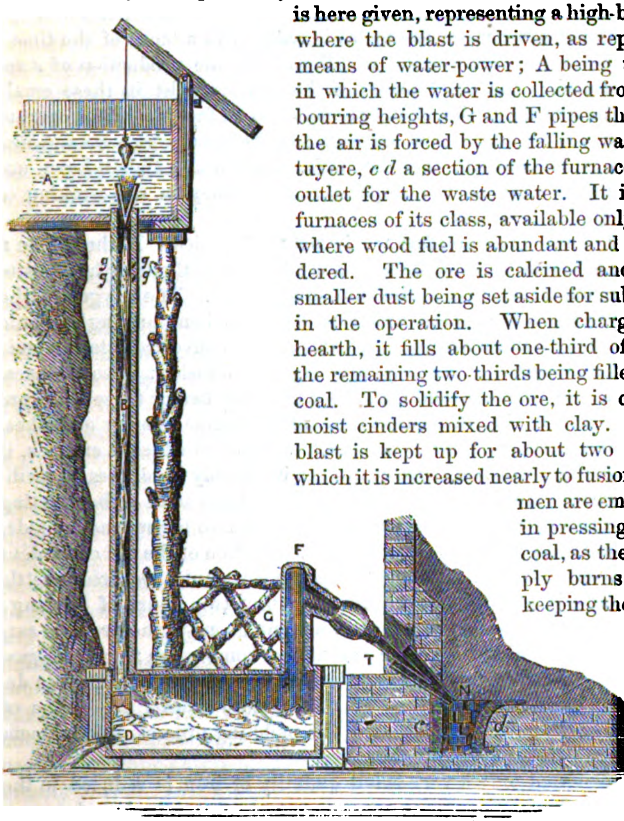

Catalan Furnace.

Much of the success of this operation depends on the skill of the attendant workman. The resulting metallic mass is composed of iron in the several states (by chemical analysis) of malleable iron, cast-iron, and steel; the relative proportions are controlled by the mode of blowing and charging the

hearth. When slowly conducted with an elevated tuyere, the production of steel is considerable; a more rapid reduction produces iron in larger quantity.

The ore for use in this furnace requires to be clean and comparatively free from extraneous matters; earthy carbonates and the majority of the ores prevailing in England cannot be profitably reduced in such furnaces. The ores are sometimes subjected to calcination, but oftener used in the raw state.

The Biscayan forge is very similar to the Catalan, a modification of which is here given, representing a high-blast furnace, where the blast is driven, as represented, by means of water-power; A being the reservoir in which the water is collected from the neighbouring heights, G and F pipes through which the air is forced by the falling water B, T the tuyere, *c d* a section of the furnace, and D an outlet for the waste water. It is, as are all furnaces of its class, available only in districts where wood fuel is abundant and cheaply rendered. The ore is calcined and sifted, the smaller dust being set aside for subsequent use in the operation. When charged into the hearth, it fills about one-third of the space; the remaining two-thirds being filled with charcoal. To solidify the ore, it is covered with moist cinders mixed with clay. A moderate blast is kept up for about two hours, after which it is increased nearly to fusion. The workmen are employed, some in pressing down charcoal, as the former supply burns away, thus keeping the hearth full, and preventing the crumbling of the ore; others in detaching the pieces of ore from the sides, and placing them in front of the blast; and in regulating the consistence of the cinder by adding more or less of the fine siftings, well watered, to prevent their blowing away with the current of gases. If the cinder is too thin, the quantity of ore-siftings added is increased; if too thick and viscid, it is diminished. The excess of cinder produced is permitted to escape through an aperture left for the purpose. The operation lasts about six hours, and



results in the production of a lump or bloom of iron, varying from 200 to 400 lb. in weight, from rather more than twice this quantity of ore.

Although accustomed to look on the African and Persian furnaces as rude and imperfect appliances, compared with the high-blast furnace, their working involves similar chemical changes; great attention is required to be paid throughout; while it must be admitted that the products it yields, after remanufacture, are the finest known samples of the metal. With the high-blast furnace, iron is reduced in large quantities, and from ores of an inferior description; but in the Persian hearth, the metal is reduced in a tenth of the time: and even this rapid rate of reduction is followed by the production of a remarkably fine metal. The great purity of the ore wrought in these small furnaces, and the quality of the charcoal employed as fuel, doubtless operate much in favour of the quality. Yet, looking at all the circumstances connected with them, it must be conceded that the native African and Indian have, unassisted by science, attained very respectable proficiency in the working of iron, so far as quality is concerned.

The theory of the blooming-furnace is not well settled. If the ore be a hæmatite, or a magnetic oxide, calcined; ore piled up on the hearth opposite the tuyere will contain the iron in the state of peroxide. The oxygen of the blast entering through the tuyere, unites with the carbon, forming carbonic acid; this gas, some writers maintain, is immediately converted into carbonic oxide. The experiments on this head are very inconclusive: in some cases, it is stated that the carbonic acid occupies a space of two or three feet from the entrance of the air; in others, that it is only the same number of inches. Without stopping to speculate as to the exact distance to which it extends, it may be remarked that the small size of the ore invariably used, greatly facilitates the reduction. The carbonic oxide (and perhaps solid carbon) acting on the oxygen of the peroxide, converts the ore, first into the magnetic oxide, then into the protoxide; and finally, with the abstraction of the last equivalent of oxygen, into metallic iron. Although direct experiment is required to settle the point, it is highly probable that during the first two hours of blowing; when a weak stream of blast is found most advantageous to the process, carbonic oxide is a principal result of the smothered combustion; and this gas, reacting for such length of time on a pulverized ore, effects its complete deoxidation. The subsequent increase of temperature causes the grains of reduced iron to agglutinate together, as in the puddling process, into a bloom capable of being moulded under the hammer.

It will be seen that only a very small quantity of iron is reduced to the liquid state of crude cast-iron; the mass is merely deoxidized, and passes, by repeated manipulations, into the state of wrought-iron. To enter at once into this state, involves the existence of a degree of purity unattainable in any blast-furnace, and seems to point to the incorrectness of the views generally held respecting the utility of particular modifications of the common form of blast-furnace; the consideration, however, of this subject, must be deferred till we come to the blast-furnace.

A modification of this process has lately been experimentally tried in the

United States; some few years since a similar modification received a trial in this country. In this modification of the old method of producing wrought iron direct from the ore, the latter is placed along with about 25 per cent. by weight of ground carbonaceous matter, in a chamber attached to a common reverberatory furnace, so as to be heated by the flues. The carbonaceous matter deprives the ore of its oxygen, which is then drawn into the chamber of a puddling-furnace; and puddled, balled, and shingled in the usual manner. The process is simply a modification of the Catalan hearth,—natural draught by a chimney and mineral fuel, being substituted for the blast and charcoal fuel of the latter. The ore is easily deprived of a portion of its oxygen; but the last equivalent clings to it with great tenacity, and requires a high temperature to effect its removal with rapidity. The process is entirely inapplicable to the poorer ores of the coal formations, and appears to be more expensive both in labour, and fuel, than the method ordinarily pursued in the reduction of the ore to malleable iron.

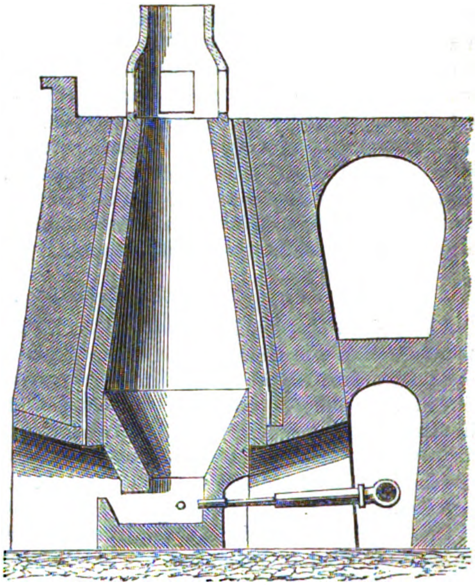
High-blast Furnace.

The modern blast-smelting furnace, in which the iron ore is converted into metallic iron, is a large and carefully-built structure, in the interior of which, complicated chemical processes of great magnitude are constantly being solved with rapidity and completeness. The interior of the furnace is usually of a circular form, approaching in sectional elevation to the figure presented by two frustrums of cones joined at their major diameters. The interior is lined with fire-brick or refractory fire-stone; and an outer casing of brick or stone is generally added.

One of the objects in the construction of furnaces is to condense the heat into the smallest possible space, in order to diminish the surface of the apparatus, and consequently the radiating surface. As regards chimneys, heat being the object sought, it ought to be preserved; the walls therefore cannot be too thick or carefully built. The height is not important, provided it rises over the buildings, and is sufficiently high to secure entire combustion, and carry the carbonic acid gas which escapes beyond the reach of doing harm. In all metallurgic operations it is essential that the chimney be wide enough for the escape of the hot gases produced; these gases, generated from different kinds of fuel, are never equal in their composition. Wood and bituminous coal, containing water, generate a large quantity of steam, besides carbonic acid; while anthracite and charcoal generate chiefly the latter, of a specific gravity of 1·52. It is evident that a greater degree of heat is required to render this product of the same specific gravity as the atmosphere, and set the gases in motion; hence the conclusion is drawn by some authors that a chimney for bituminous coal requires to be larger than one for either wood fuel, anthracite, or charcoal.

In order to economise the heat, the interior of the chimney should be perfectly smooth—the bricks so far refractory as to resist vitrification or melting under the heat to which they are exposed. The accompanying figure shows the vertical section of a modern blast-furnace, where the masonry is constructed

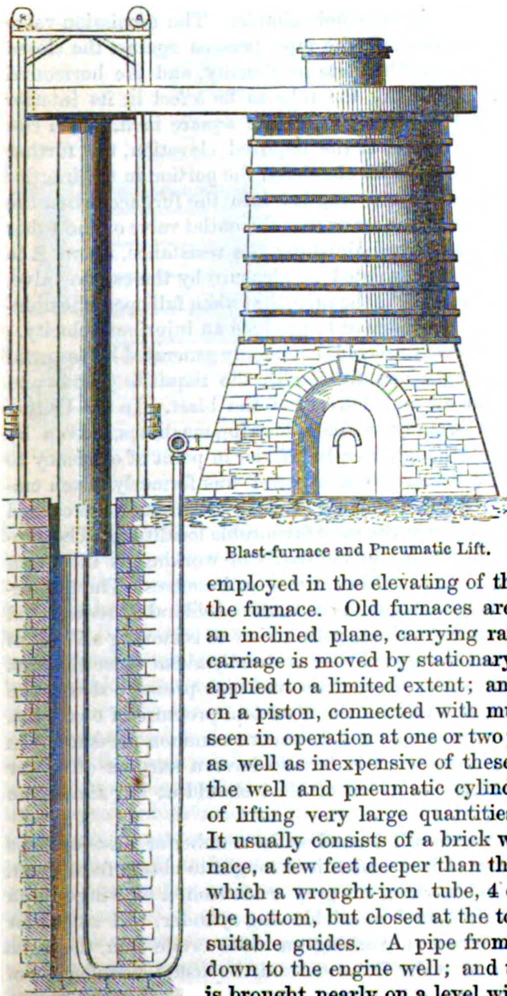
of rough sandstone. The interior is formed of fire-proof materials, either sandstone or fire-brick. It is also important to have efficient means of drainage, as it is desirable that the bottom part of the furnace should be dry and warm. At the bottom, orifices are constructed in the brickwork for the insertion of the blast-pipes, and one in front for the discharge of the liquid iron and cinder; the latter escapes over a dam-stone or plate, the top of which is nearly on a level with the under side of the blast-pipes. The orifice for the metal, on a level with the bottom or hearth of the furnace, is closed between the castings by a lute of fire-clay or sand; those for the admission of the compressed air are lined with sheet or cast tuyere-irons, kept cool by a small current of water circulating in the metal. Compressed air, or "blast" as it is commonly called, is brought from the blowing engines in large metal pipes, from which smaller pipes branch off to each of the tuyere orifices in the furnace, where they terminate in the tuyere-iron in a slightly tapered pipe. The top is open, with the exception of a brick chimney, pierced with openings for the insertion of the materials, to protect the attendant workmen from the intense heat. The exterior of the furnace is variously shaped: square is a very general form in Wales, where building-stone is inexpensive; while the square base and circular top is the prevailing form in Staffordshire and Scotland. As a general rule, the exterior form is perfectly immaterial to the working of the furnace, so long as it prevents the radiation of heat, and is bored in such a manner as to retain its form unaltered under great changes of temperature.



Section of a Blast-furnace.

The dimensions of blast-furnaces vary greatly; and the several proportions of the interior, on which much undoubtedly depends, are made without any rule or method. This inattention to general principles is not confined to England. In the North American States, where the iron trade has advanced with strides almost equally rapid, furnaces working on similar minerals are built of all dimensions between 8 and 22 feet diameter; in the height, greater regularity is observed; the extreme range in that country lying between

30 and 45 feet. In England the furnaces range between 9 feet diameter by 25 high, the smallest of the anthracite; to 20 diameter by 50 high, the largest in other districts. The throat of modern furnaces is comparatively large, a proportion of one-half of the largest diameter being now common. A similarly large throat is seen in the anthracite furnaces of America; but the charcoal furnaces work with small throats, often not more than 20 or 30 inches. The exterior size of furnaces is subject to the same caprice as the interior. Forty feet is a common size at base, but they may be seen as small as 20, and so large as 50 feet.



Blast-furnace and Pneumatic Lift.

The situation of the furnaces in the neighbourhood of steep hills, has been taken advantage of in Wales to bring the materials on to the top without recourse to machinery. In Staffordshire and other districts, in the absence of similar natural advantages, various appliances have been employed in the elevating of the materials to the level of the furnace. Old furnaces are commonly wrought with an inclined plane, carrying rails, over which a platform carriage is moved by stationary power. Water-power is applied to a limited extent; and the pressure of the blast on a piston, connected with multiplying gearing, may be seen in operation at one or two places. The most effective as well as inexpensive of these appliances appears to be the well and pneumatic cylinder, an apparatus capable of lifting very large quantities to any required height. It usually consists of a brick well, in the rear of the furnace, a few feet deeper than the height of the furnace, in which a wrought-iron tube, 4 or 5 feet diameter, open at the bottom, but closed at the top, works up and down in suitable guides. A pipe from the engine main, passes down to the engine well; and turning up inside the tube, is brought nearly on a level with the surface. The pipe has a suitable valve to regulate and stop the admission of blast. Water fills

the well to within a few feet of the surface, forming an air-tight joint around the pipe, in its ascent and descent. The upper end of the tube is furnished with an outlet-valve, and also carries a platform, on which the loaded barrows are supported. This platform works in a framework of guides; and its weight, and that of the tube, are nearly balanced by weights attached to chains passing over pulleys at the top.

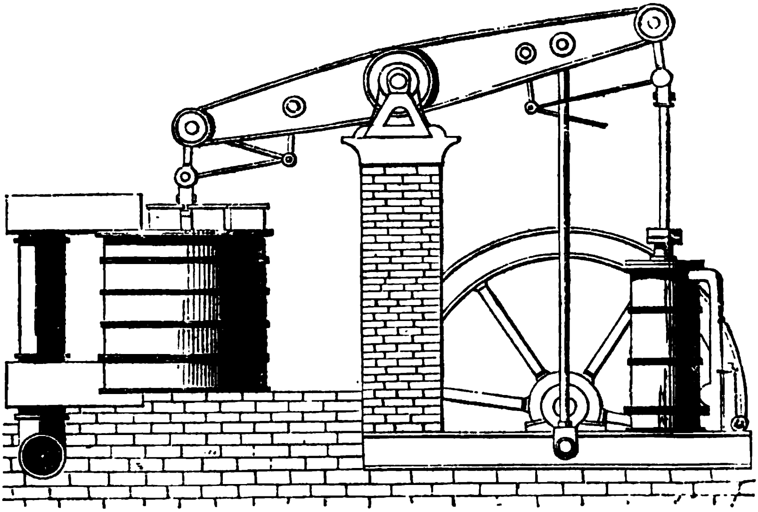
The working of the apparatus is extremely simple. The admission-valve is opened, and the blast passing through the pipe, presses against the closed end of the tube, with a force proportional to its density, and the horizontal area exposed to its action. Assuming the tube to be 5 feet in its interior diameter, and the pressure of the blast 3 lbs. to the square inch, it will rise with a force of 8481 lbs. On arriving at the required elevation, the further admission of blast is shut off, and by its elasticity, the portion in the interior buoys up the tube until the barrows are emptied into the furnace, when the descent is accomplished, by opening, more or less, the outlet-valve on the tube; the escape of the confined blast, by diminishing the resistance, allows it to descend. The rate of descent is regulated at pleasure by the escape-valve, which is made of such a size, relatively to the tube, that when full open, the uninterrupted flow of blast will not be sufficient to produce an injurious velocity.

The "blast" for urging the blast-furnace is commonly generated by powerful steam-engines, working metal cylinders, fitted with the requisite pistons and valves for the admission of the air and delivery of the blast. In the United States, and some parts of Germany, wooden blowing-machines, driven by water-power, are very general, though greatly inferior in point of efficiency to the steam-engine and metal cylinder. Water-power was formerly much employed in England; but the frequent deficiency of water, in summer, has caused it to be superseded by steam, even in the most favourable localities. The simplest form of engine, with due regard to regularity of working, is the beam high-pressure, having a heavy fly-wheel to carry it over centres. The proportions of the parts belonging to the steam-end are made considerably heavier and stronger than for ordinary steam-engines, with a view of removing all risk of accident from weakness: the blowing cylinder is usually about twice the area of the steam cylinder. With these proportions, and high-pressure steam, the engine will be perfectly able to compress the blast to a pressure of 6 or 7 lbs. to the square inch, though in practice 3 lbs. is a more common pressure. In erecting a blowing-engine, however, it is best to have a surplus of power on the steam side, in case a high pressure of blast should at any time seem advisable.

The size of the blowing-engine will depend on the number of blast-furnaces in operation, and the quantity of iron which it is sought to obtain from them. If the furnaces are small, and working on gray crude iron, a blowing-engine of the largest class, viz. with a twelve-feet blowing-cylinder, will suffice for ten or twelve; with larger furnaces, working on white crude iron, the same engine will suffice for seven or eight furnaces, and the usual complement of blast refineries. To blow so many, however, it is necessary that the engine should be driven at a minimum speed of 400 feet per minute, and be furnished

with sufficiently large mains, and numerous and sufficiently large blast and delivery valves.

Where quantity is sought irrespective of quality, a modern invention for

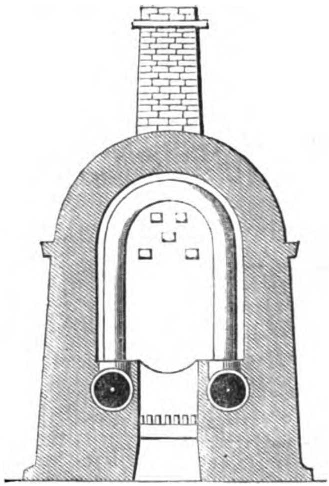


Elevation of High-pressure Blowing-engine.

heating the blast is very generally adopted. Over a fire-place a series of cast-iron pipes of an arched form are mounted on two horizontal pipes, in the one of which cold air enters, and, passing through the arched pipes, absorbs from the heated metal a large accession of temperature before entering the furnace By placing over the fire-place, the requisite number of arched pipes, a sufficiently large surface is exposed to the action of the fire underneath, to heat the blast, in its rapid passage, to a temperature equal to the melting-point of zinc. In the earlier furnaces to which the invention was applied, a large pipe was exposed to the fire, several yards in length; but the low temperature to which the blast was heated led ultimately to the adoption of a number of smaller pipes of a sectional form, offering a large surface to the heat; through these pipes the blast is forced in a number of thin streams. With this provision, from the rapid rate at which the blast is propelled, namely, from 3000 to 6000 feet per minute, or 35 to 70 miles per hour; it is apparent that atmospheric air is capable of receiving an accession of nearly 700 degrees of temperature in less than one second of time—a rapidity perfectly marvellous, compared with the general slowness of natural phenomena.

The arrangements followed in the production of crude iron with the high-blast furnace, consist in filling into the throat at top; ore, fuel, and flux, and supplying blast through the tuyere orifices at bottom. The combustion of

the fuel generates a sufficiently high temperature, to fuse the adjacent pieces of ore, and flux, thus liberating metallic iron, which descends into the lower hearth, from whence it is allowed to flow away through the tapping-hole at stated times in the day. The lighter portions of the liquid matter, comprising the cinder, floats on the metal, and flows over a notch in the dam-stone into a suitable receptacle, so as to solidify, previous to removal. The attendants at top have to fill regularly and evenly, over all the material in the furnace, as fast as it descends by fusion; while those at the bottom are occupied in withdrawing the metal, attending to the cinder, and clearing the tuyere orifices, so that no obstruction may be opposed to the entrance of the blast.



Heating Stove.

Consumption of Material.

The quantity of ore required to produce a ton of iron varies with its richness. Of the earthy carbonates of the coal-measures, and the ores of the oolitic formation, there are required about 60 cwts.; of the hæmatites of Dean Forest and Cornwall, about 46 cwts.; while of the Lancashire and Cumberland ore, 38 to 40 produce a ton of iron. The fuel ranges from 30 to 50 cwts. and upwards, depending, partly on the quality and hardness, but more on the economy of the furnace. The flux for the earthy carbonates consists of limestone or chalk, added at the rate of 12 to 18 cwts. per ton of iron; for the calcareous ores of the mountain limestone formation, shale bands of the coal-measure are used for the formation of a sufficiently fluid cinder. This substance is also added to the rich hæmatites, to compensate for the deficiency of earthy matters for forming the necessary cinder. The quantity of solids thus charged into the top, amounts, on an average, to 6 tons for every ton of crude iron obtained.

The quantity of air blown into the bottom of the furnace may be estimated by weight at 13 tons for each ton of iron made; whence it follows that the total weight of the solids and gases brought into action in the reduction of one ton of iron, amounts to 19 tons. In the blast-furnace, this is rapidly resolved into liquid matter, weighing about 3 tons, which escapes at the bottom; while gaseous matters, weighing nearly 16 tons, ascend the furnace, and escape at the top.

Reactions in the Chemical Laboratory of the Blast-furnace.

Assuming the furnace to be filled with ore, fuel, and flux, in the proportions which an analysis of each has determined to be most suitable, the chemical

changes may be said to commence with the entrance of the (cold) blast into the furnace. The composition of atmospheric air, with an average amount of moisture, may be taken as follows :—

Oxygen	21·00
Nitrogen	77·50
Aqueous vapour . . .	1·42
Carbonic acid	·08
	100·00

Nitrogen, which is the largest constituent, appears to undergo no alteration, merely passing through the incandescent materials in the furnace, and escaping at the top; while oxygen, the next largest constituent, on entering the hearth of the furnace, combines with the fuel there present, and at a few inches from the tuyere is converted into carbonic acid; ascending through the ignited fuel, the carbonic acid is partly or wholly converted into carbonic oxide. A portion of this gas deprives the ore of its last equivalent of oxygen, and is converted back to carbonic acid; in its further ascent, upwards to the throat, it is influenced by the temperature of the surrounding materials. If these are at a high temperature, the carbonic acid unites with the carbon of the red-hot fuel, and escapes at the top as carbonic oxide; if the temperature is low, it is unaltered, and escapes as the carbonic acid. A second portion of the carbonic oxide first formed, abstracts the second equivalent of oxygen from the ore, and passes upwards in a similar manner; while a third portion passes unaltered to near the throat, where it deprives the ore of its first equivalent of oxygen.

The aqueous vapour is decomposed, the liberated oxygen uniting with the main body of oxygen in the air, while the hydrogen ascends to the top. It is commonly stated that the small quantity of this gas which thus ascends, is without influence on the operations of the furnace; but this statement requires confirmation by direct experiment. The minute quantity of carbonic acid in the air acts in the same manner as the larger volume produced by combustion of the carbon.

Chemical change in the composition of the calcined ore, commences immediately on entering the furnace. After calcination it is of an open porous structure, readily permeable by gases; on entering the throat, the ascending carbonic oxide deprives it of one equivalent of oxygen, leaving it as a magnetic oxide. In this state the ore descends the furnace to the more elevated temperature of the hearth above the tuyeres; the carbonic oxide now abstracts a second equivalent of oxygen, and immediately afterwards the ore yields its last portion of oxygen, and descends into the hearth below the influence of the heat. If the ore contains water, it is vaporized at the top, and escapes as steam.

The fuel (coke) in the upper part of the furnace is absorbed to a great extent in the production of carbonic oxide, and also by the destructive velocity of

the gases in the narrow throat. The width of this part of the furnace materially influences the consumption of fuel. Lower down, the fuel supplies carbon to the carbonic acid, to form carbonic oxide for the deoxidation of the ore, and for union with the metal as a carburet; the portion of fuel which has escaped consumption in the descent, is converted into carbonic acid in the region of the tuyere.

The change produced in the limestone flux, appears limited to the expulsion of its carbonic acid, which is effected, in the case of small stones, in the neighbourhood of the throat; with larger stones its entire expulsion is effected at a greater depth in the furnace.

The chemical changes result in corresponding variations in the temperature of the ascending current of gases. The oxygen of the external air, on entering, combines with the remaining carbon of the fuel, liberating a large amount of caloric, which is taken up by the ore, flux, and gases. The intensely high temperature in this part of the furnace continues to the level where carbonic oxide is formed; a slight temporary diminution now takes place; it is partially restored by the reconversion of carbonic oxide, into carbonic acid in the deoxidation of the ore. The temperature slightly decreases to the level where the flux evolves its carbonic acid. The quantity of heat, rendered latent at this level, produces an immediate reduction of temperature. The conversion of the water into steam, combined with the ore and fuel, also tends to a diminution of temperature in this region. In consequence, however, of the small bulk of material at top, the rapid draught there created, results in a partial combustion of the fuel, and the maintenance of a higher temperature than otherwise would be the case.

During the passage of the gases through the furnace, the reduction of temperature at each level, consequent on the formation of carbonic oxide, and the large influx of carbonic acid from the limestone, is much less than has been stated by some writers. Very mistaken views on this subject have arisen from their treating the upward current as consisting, at the lower level, of carbonic acid, and from estimating this current as being converted into carbonic oxide, when necessarily a large reduction would ensue. In reality, the upward current of gas just above the tuyere consists of carbonic acid, with about twice its weight of nitrogen. This nitrogen, though offering no chemical affinity in its ascent, plays a most important part in the economy of the blast-furnace. Heated at the low level to the intense temperature there prevailing, it acts throughout its ascent, as a medium for equalizing the temperature. At the first reduction, the conversion of the carbonic acid into carbonic oxide, and the large store of heat in the nitrogen, is drawn upon, to supply the larger portion of the difference that otherwise would take place. In the subsequent charges to the throat, the nitrogen is called upon to yield up other portions of the heat which it absorbed at the low level.

The heat, rendered latent by so much carbonic oxide as unites with the oxygen of the ore, is recovered again in the formation of carbonic acid; therefore a temporary depression only is created by this portion of carbonic oxide.

Temperature in the Blast-furnace.

The Hearth.—In this part of the furnace, it must be obvious that the maximum temperature will be mutually dependent on the blast, fuel, and facilities for absorbing the heat developed. With the required volume and density of blast, according to the amount of fuel, the production of a low or high temperature, up to the highest temperature attainable with atmospheric air, will be solely dependent on the facilities afforded for its absorption. The ore and flux are the materials which should absorb the heat developed; according, then, to the proportion which they bear to the heat evolved, will the temperature be high or low. If the ore and flux are in excess, the rapid manner in which they absorb the quantity of available caloric, results in a low temperature; on the other hand, when they are small in quantity, the caloric evolved accumulates, and the materials naturally acquire a higher temperature from inability to absorb the whole of the caloric, at the low temperature.

By heating the blast before its admission to the furnace, a quantity of caloric is directly communicated, in addition to that produced by combustion of fuel within the blast-furnace; the excess of caloric thus thrown into the furnace, results in a direct accession of temperature, until the additional caloric absorbed by the materials is equal to that communicated by the heated blast. It must be borne in mind, however, that the accession of temperature by the heated blast, over that resulting from the cold blast, is entirely dependent on the maintenance of the former relation of blast, to fuel in the furnace. If the fuel burden is diminished in greater ratio than the increased quantity of heat communicated by the heated blast, the lesser quantity of caloric in the hearth of the furnace results in the prevalence of a lower temperature. In the superior regions of the furnace, the use of heated air, with its accompanying reduction of fuel-burden, results in a permanent reduction of temperature compared with that in the cold-blast furnace, while the gradations from zone to zone are more abrupt. The lesser quantity of air thrown into the hot-blast furnace, relatively to the ore and flux, results in a proportionately smaller quantity of nitrogen being heated in the hearth; and the volume of gases throughout, is similarly reduced. Consequent on this diminution of hot gases, in proportion to the quantity of ore and flux, the ascending current is more rapidly deprived of its caloric, and escapes at the throat at a very much lower temperature than in cold-blast furnaces. The lesser quantity of nitrogen is also seen to be prejudicial, inasmuch as it is less able to compensate for the diminution of temperature which follows on the conversion of carbonic acid into carbonic oxide.

This general inferiority of temperature is borne out by direct experiment in the throat of furnaces of both descriptions.

A common and very prevalent error is to suppose, that the mere heating of the air, results in an accession of temperature in the blast-furnace, without reference to the fuel which may be consumed therein, or the quantities of blast delivered for its combustion. Were this the case, hot-blast furnaces would invariably produce gray iron, with a cinder nearly devoid of oxide of

iron—the invariable products of a high temperature and dry materials; but it is well known that such furnaces more often produce white iron, and scouring cinder, the usual attendants on a cold furnace.

Disposal of Heat in the Blast-furnace.

The carbon of the fuel used in the blast-furnace, is variously consumed: a portion—by very much the largest, indeed—is expended in generating the high temperature of the hearth; a second portion is consumed in effecting the deoxidation of the ore; while a third and smaller portion combines with the metal as carburet. The quantity combining with the metal may be taken as averaging 3 per cent. of its composition, or 67·2 lbs. per ton of crude iron. The quantity absolutely required for the deoxidation of the ore is determined by the quantity of oxygen in combination with the latter. Assuming the ore to have been calcined, the metal will exist as peroxide; or for 2240 lbs. of iron, there will be 960 lbs. of oxygen. To convert this into carbonic acid requires a consumption of 360 lbs. of carbon: added to the previous quantity, a total of 427 lbs. has to be deducted from the consumption of fuel for the carbon thus absorbed.

The average consumption of coke may be estimated at 32 cwts., equal to 30 cwts. of pure carbon: deducting 427 lbs. from this, there remain 2933 lbs. available for fusing the ore, and flux, and as compensation for loss in various ways.

By experiment, it appears that the fusion, to perfect liquidity, of 3 tons of material, in the proportion of 1 ton of iron and 2 tons of cinder, determines the absorption of an amount of caloric, equal to that evolved during the conversion of 380 lbs. of carbon into carbonic acid. The carbonic acid absorbs a similar amount of carbon during its reduction to carbonic oxide; but, as credit has previously been taken for 360 lbs. thus consumed, there remains only 20 lbs. to add to the 380 as the quantity carried off by the heat of the liquid products underneath. A further consumption of heat occurs in the upper part of the furnace, through the evolution of the carbonic acid of the limestone. Estimating the consumption of limestone at 15 cwts., the carbonic acid liberated will amount to about 6¾ cwts., which is accomplished by the heat of 45 lbs. of carbon, burnt to carbonic oxide. Hence the total consumption of carbon under these heads, amounts to 872 lbs. This represents the total amount of carbon, utilized out of a consumption of 3360 lbs., leaving a loss of 2488 lbs. to be accounted for. Radiation from the interior, escape of gases at the tuyeres, and heat abstracted by the water circulating in the tuyeres: all these diminish, to a proportionate extent, the effective quantity of carbon, the aggregate loss from these circumstances being under 100 lbs.; but the great bulk, exceeding two-thirds of the quantity thrown into the furnace, is utterly lost at the throat.

The medium in which it escapes are the gases issuing in large quantity from the throat at a high temperature. It has been stated, that while the product of molten iron and cinder from the bottom weigh but 3 tons for 1 ton of iron, the gases escaping at top weigh 16 tons. After carefully comparing the high specific heat of these, it is manifest that to elevate them to the tempera-

ture of the throat, a quantity of heat is absorbed nearly equal to that yielded by the combustion of the 2488 lbs. of carbon otherwise unaccounted for. The superior capacity of gases for caloric has been overlooked in the economical arrangement of the furnace, and enormous quantities of fuel are thus constantly being dissipated in the gaseous products liberated into the atmosphere.

The loss from this cause explains the superior economy of fuel in wide-throat furnaces. The blast-furnaces of Scotland of a former date had very narrow throats, and consumed large quantities of fuel compared with the work done; at the same period, furnaces in South Wales, having comparatively wide throats, were worked with less than one-half the amount of carbon consumed in the Scotch furnaces. The beneficial effects resulting from large throats have lately been made apparent in other districts; and a very general enlargement of this part has taken place within the last few years, followed in every case by a corresponding economy of fuel. The large throat diminishes the consumption of fuel in two ways:—1stly, by offering a larger mass of material for absorbing the available heat of the ascending gases;—2ndly, by reducing the temperature of the gases for a short distance below the top, they exercise a less destructive influence on the fuel in the throat. The immense volume of gases rushes through the materials in this region with a velocity ranging up to 200 feet per second. By extending the width still further, the reduction may be lowered to half the present consumption, and yet leave a surplus of heat for all the requirements of the furnace.

Since the publication of his large work, wherein the author entered into numerous details on this subject, several furnaces have been erected with the top 13 and 14 feet diameter. The extraordinary performance of these will perhaps eventually lead to the adoption of his other views in regard to the economy of fuel attainable by a proper construction of furnace.

By some authorities, the cool top is held to be disadvantageous, inasmuch as it determines the expulsion of the carbonic acid of the limestone at too great a depth in the furnace, and renders latent a considerable quantity of heat at a low level. This objection, however, does not occur in practice, for after descending through the upper layers of material, the temperature of the two furnaces is nearly similar. The present high temperature in that portion of the furnace is altogether unnecessary to the chemical changes which should there take place. The carbonic acid of the limestone is expelled at a much lower temperature; while the abstraction of the first equivalent of oxygen from the ore takes place very rapidly under the dullest red heat. The best argument, however, that can be adduced in favour of the correctness of the views first advanced by the author, is the large increase in this part of the furnace which has already taken place without injury to the operations. At the commencement of the present century, the majority of the furnaces of South Staffordshire had throats under 36 inches across: now 8 feet are not unusual dimensions; yet with this increase from an area of 9 to 64 feet, more than 7 times the former area, there has been no difficulty in working the furnaces, but the reverse; while the economy of fuel attending the alteration has been very great.

A difficulty of filling has been urged against wide-throat furnaces; but with a corresponding increase in the number of charging places, or, what is better, by filling with the shovel, the materials may be distributed over the interior with the greatest regularity. The supposed difficulty of filling has ever been adduced as a reason against any enlargement; nevertheless, the throat has increased from 3 to 8 feet, and within the present year to 13 and 14 feet, without injury to the working of the furnace. In the case of the American charcoal furnaces a similar dread exists against any alteration; and the consumption of fuel is proportionately large.

In connection with this subject, it may be remarked that there is no relation between the consumption of fuel and the economical products obtained. The quantity of fuel required to produce a ton of crude iron, varies not only in different districts, but in different works in the same district; and not unfrequently a considerable difference is observed in the furnaces of the same firm. The richness or poverty of the ore, also the quality and quantity of the flux, though resulting in a less or greater quantity of matter for fusion, are circumstances which have no perceptible influence on the consumption of fuel. The leanest ores of South Wales are smelted with nearly as great economy of fuel as the richest. Clearly the heat yielded by the fuel is for the purpose of liquefying the ore and flux; and the amount of these determines the quantity of fuel utilized for that purpose. The consideration of the manner in which the heat developed is disposed of, accounts for the little influence exercised by the quantity of liquid products on the yield of fuel. It is seen that the caloric absorbed by each ton of molten matter is represented by the heat obtained from 130 lbs. of carbon. Hence the variation in the yield of fuel, consequent on the change from a rich to a poor ore, or *vice versa*, can scarcely be more than twice this quantity, or 260 lbs. of carbon for each ton of liquid material obtained. The fact that this slight increase in the quantity of fuel suffices in practice to melt an additional ton of matter, demonstrates the correctness of these views regarding the great loss of heat in the common blast-furnace.

A smaller quantity of fuel is used when heated air is employed, though, after deducting the quantity used in the heating-stoves, the reduction is not very considerable. Until recently, the most erroneous ideas prevailed respecting the economy of fuel by the use of heated air. In several instances it has been stated, that by its use alone the consumption has been reduced from 8 to 2 tons, per ton of pig-iron produced; at the same time it is known to practical men, that in the present blast-furnaces the amount economised is at the outside scarcely 5 cwts., and very many furnaces are now working with cold air, with greater economy of fuel than others using heated air. This discrepancy in the results, from an invention which is largely used on the Continent, as well as in the United States, has been variously accounted for.

In Scotland, where the use of heated air at one time effected a large diminution in the consumption of fuel, amounting, according to several writers, to some tons for every ton of iron made, the furnaces are now frequently blown for short periods with cold air, with an increased consumption of fuel of no

more than 5 cwts. per ton over that consumed with heated air. This alteration in the benefits accruing from heated air evidently arises from the successive improvements in smelting made in that country, by which it has attained to nearly as great proficiency as other parts of the United Kingdom.

The cause of the saving of 5 cwts. of fuel by the use of heated air, is seen in the altered circumstances in which the products of combustion escape into the atmosphere. The heat is imparted to the blast in the stove-pipes with a small waste of caloric, for the products escape from the chimney of the stove with a temperature less by one-half than the temperature of the throat of the cold-blast furnace. The diminished loss of caloric in this way, and the less destructive influence exercised by the smaller current of gases on the heated fuel, results in the loss of heat being proportionately less.

The Gaseous Current in Blast-furnaces.

Researches into the composition of the gases in English, German, and French furnaces have been made; but the results are so widely different, that it is very doubtful if they correctly represent the chemical changes taking place in the interior. The nitrogen of the atmosphere appears to ascend unacted upon, and consequently affords a ready standard for measuring the variations in the quantities of the other gases. The oxygen in the escaping gases, for instance, is derived from the blast entering at the tuyeres, increased in its ascent by as much as enters with the oxide of iron and carbonate of lime at top. On referring to the chemical changes which occur to the ore, it is seen that the quantity of oxygen in the current, relatively to that of nitrogen, is necessarily increased on arriving at the surface of the materials. The English experiments, however, do not exhibit that regularity in the increase which occurs in practice. The varying proportion of oxygen to nitrogen in the ascending column, appears to have been as follows in Messrs. Bunsen and Playfair's experiment with the Alfreton furnace:—

Depth from top.	Nitrogen.	Oxygen.
5 feet	77·0	32·9
8 "	77·0	31·3
11 "	77·0	35·1
14 "	77·0	32·9
17 "	77·0	34·5
20 "	77·0	29·8
23 "	77·0	36·0
24 "	77·0	36·3
34 "	77·0	28·4

The last depth was 2 or 3 feet above the tuyere. To accord with the known changes in the ore and flux, the quantity of oxygen should have exhibited an increase in each line in an ascending series. The difficulties attending the withdrawal from the centre of the furnace of gas in sufficient volume for examination, was probably the cause of these discrepancies, and must continue a serious obstacle to more accurate determinations.

The results of the experiments made in France are more in accordance with other researches on the chemical changes produced by gases out of the blast-furnace. Objection, however, has been taken to their correctness, especially to the method pursued in analyzing the collected gases. At successive depths in the furnace, the proportion of oxygen to nitrogen, in the ascending gases, was—

Depth from top.	Nitrogen.	Oxygen.
0·0 feet.	77·0	36·3
4·3 „	77·0	38·2
8·7 „	77 0	37·8
13·1 „	77·0	34·0
17·4 „	77·0	27·6
18·6 „	77·0	24·5
Above tuyere . . .	77·0	22·9

Here the increase in the quantity of oxygen corresponds with the levels at which the ore is deprived of this constituent. In the first three lines ascending, the increase of oxygen is small—from 22·9 to 24·5; and from 24·5 to 27·6 represents nearly the quantity accruing from the last and second equivalent of oxygen. Ascending still higher, the increase to 34·0, and finally to 38·2, is due to the abstraction of the first equivalent of oxygen from the ore, the large influx of carbonic acid from the flux, and the moisture entering with the fuel and ore.

The occurrence of carbonic oxide—a combustible gas, escaping in considerable quantity with other gases from some blast-furnaces—has resulted in numerous attempts to apply it to heating purposes, but hitherto with little success. The gases have been applied to raising steam, heating the air, calcining the ore, and other operations requiring a low heat. Theoretically, the carbonic oxide should yield a large quantity of heat on combustion with atmospheric air; but owing to the comparatively large amount of nitrogen which has to be heated along with it, the available caloric scarcely exceeds the sensible heat of the gases at their escape from the top of the furnace.

The propriety of interfering with the gases at all is now very much questioned; and circumstances seem to warrant the conclusion, that carbonic oxide in considerable quantity in the escaping gas indicates defects which suggest remedial measures for overcoming them, rather than the endeavour to turn the carbonic oxide to account as a fuel. It is observed, that furnaces working with great economy of fuel discharge very small quantities of this gas; while others of a more imperfect construction, and consuming large quantities of fuel, in proportion to the work done, discharge nearly the whole of the carbon consumed, combined with the oxygen as carbonic oxide. Even the carbonic acid of the limestone, in passing through the highly-heated fuel in the throat, is converted into carbonic oxide.

On the Continent, and in the North American States, the gases are very generally controlled and utilized in various ways: yet is the consumption of fuel higher than in this country, notwithstanding the superior richness of the

foreign ore, and the small quantity of flux used. In the South Staffordshire district, all attempts to control the issuing of the gases have resulted in injurious disturbances on the furnace, to such an extent as to lead to an immediate return to the former method of working. Numerous experimental trials have been made, all of which, with but one exception, have resulted in serious loss; and scarcely greater progress appears to have been made in other districts.

Quantity of Metal obtained from a Blast-furnace.

The make or quantity of iron resulting from a blast-furnace, is principally dependent on the quantity of blast delivered into it, and the relative proportions of ore and flux to fuel. With a fixed burden of fuel relatively to that of ore and flux, the make will be proportional to the quantity of blast delivered, without reference to its temperature. On the other hand, with a fixed volume of blast, the make will be inversely as the quantity of fuel to ore and flux, within the limits of fluidity.

The descending column of solids, in the interior of a blast-furnace, consists of ore, flux, and fuel, in suitable proportions; and though composed of ingredients of different density, yet, by their admixture at top, they descend *en masse* to the bottom. The descent of this column is determined by the rapidity or slowness with which the fuel is consumed: since this is effected by the oxygen of the blast, the quantity admitted regulates the descent. By diminishing the proportion of fuel in the column, the descent is accelerated, in consequence of the blast effecting the combustion of the same quantity of fuel as previously. Under such circumstances, the make may be diminished at pleasure, by diminishing the quantity of blast, or increasing the proportion of fuel to ore and flux; by the reverse of this it may be increased to the highest quantity compatible with the production of a sufficient amount of heat to maintain perfect fluidity.

These considerations demonstrate the incorrectness of the opinion that a mere heating of the blast results in an augmented make. It is obvious that to attain the increase, the quantity of fuel must be reduced. The heated blast contains only the same quantity of oxygen as when cold; and it is clearly impossible that it can of itself accelerate the descent of the column, or otherwise influence the production of iron, so long as the latter remains liquid.

Quantity and Pressure of Blast.

The quantity of blast is determined by the capabilities of the furnace and the kind of iron sought to be obtained. If the furnace is of the largest class, provision should be made for a quantity up to 14,000 cubic feet of air per minute. The more rapidly the gases ascend the furnace, the whiter the iron. With white iron they pass through the furnace in three or four seconds; with gray in ten or twelve seconds. When it is desired to produce gray iron, a smaller volume of blast is employed, along with an increased burden of fuel; this causes the column to descend more slowly. But the employment of a sufficiently reduced volume of blast will of itself cause a change in quality from white to gray, with a corresponding reduction in the make of pig-iron.

The pressure of blast best suited to the requirements of the furnace is dependent on circumstances, to which great attention should be paid. The first of them is the width of the hearth. The diameter of the furnace at this place being fixed, the pressure of the blast has to be such that it may penetrate the full extent of the mass of material; supplying oxygen to all the fuel on a level with the tuyere. With narrow hearths a low pressure suffices, but wide hearths require a high pressure.

The density of the fuel also influences the pressure of the blast. Fuel of a low specific gravity cannot be worked with a dense blast in narrow hearths; while fuels of a denser description require the strongest blasts attainable. The lightest fuel used in smelting is charcoal, which is wrought with blasts whose pressure is about half a pound to the square inch. With this low pressure an intense heat is obtained, because the large surface which the charcoal exposes to the oxygen of the blast, is eminently favourable to rapid combustion. Anthracite, on the other hand, is the most dense fuel used in smelting, and demands a strong blast in order to bring the oxygen and carbon into contact with sufficient rapidity.

The density of the fuel also determines principally the width of the hearth; it also, to a certain extent, determines that of the furnace. Charcoal can only be profitably employed in very narrow hearths: too weak to support a strong blast, the breadth is necessarily limited to the range of the weak blast employed. The pressure and volume of the blast is likewise influenced by the lightness of charcoal, compared with the ore and flux. This circumstance necessitates a due regard being paid to the velocity of the ascending gases, the pressure of which in the narrow hearth may exceed the gravitating influence of the light charcoal, and prevent its regular descent to the tuyere.

Quality of the Crude Iron.

The commercial quality of the crude iron reduced in the hearth of the furnace, is indicated with considerable accuracy by the cinder which flows over the dam-stone. Furnaces burdened with the carbonates of the coal measures, when working well, yield a cinder having a stony-gray fracture in the interior, and a deep brown vitreous appearance externally. Occasionally the presence of particular oxides produces various shades, between gray and azure blue, in the interior. The gray cinder usually indicates metal of a superior quality; numbered 1, 2, or 3. Cinders of a colour brown in the interior, and blackish-brown outside, generally accompany iron of a lower quality, mottled or white; while such cinders as are of a black colour throughout, invariably accompany iron of the lowest quality. These are technically termed "scouring cinders," and contain a large quantity of oxide of iron, indicating a cold unhealthy condition in the great laboratory of the blast-furnace. If allowed to flow for a considerable time, they injure irreparably the brickwork of the boshes and hearth; and by cooling the interior, endanger the safety of the furnace. Gray cinders sometimes flow with a white iron burden; but their constant production under such circumstances requires great

attention, dry materials, and a favourable furnace. An excessive burden of ore is invariably accompanied with white iron and scouring cinder.

In the casting-bed, the quality is shown very correctly by the surface of the bars of pig-iron, technically termed "pigs." The gray and superior qualities present a smooth round face, and maintain their fluidity, so as to run into thin sheets; the lowest qualities have a rough, pitted, concave surface, and run thick and sluggishly.

The chemical composition of the iron and cinder produced by a blast-furnace, is dependent on the composition of the ore, fuel, and flux, and, to a varying degree, on the method of reduction pursued, and whether by a hot or cold blast, or by a controlled or uncontrolled escape of the gaseous product at top. Probably amongst these influences, the quality of the ore is greatest. The carbon, a powerful and invariable contamination in iron, varies with the mode of working and the quantity of fuel consumed, increasing nearly in the same ratio as the consumption of fuel. The analyses of three samples of cast iron will show very clearly the composition of the crude-iron of the blast-furnace.

	A	B	C
Iron	94·57	89·75	95·618
Silicon	1·30	2·02	1·012
Carbon	2·06	1·88	1·590
Sulphur	·09	1·23	·640
Phosphorus	faint traces	1·52	·820
Manganese	1·36	4·13	1·200
Calcium	·60	·21	·320
Magnesium	·11	·05	traces.
	100·09	100·79	101·200

These three analyses are by Mr. Crowder. A is a No. 1 foundry iron, from Merthyr Tydfil; it fairly represents the average character of the Welsh cold-blast No. 1 foundry irons, smelted from the best local ores, without any admixture of hæmatite, and with due regard to the purity of the fuel. B and C are white forge-irons; the first from a furnace in the Ebbw Valley, and the second from the Blaina Valley, in Monmouthshire. They are average specimens of crude iron manufactured with heated blast, a small burden of flux, and a mixed ore burden. In both cases the furnaces are wrought with the top closed, for the purpose of collecting and utilizing the gas which remains unconsumed.

The cinder accompanying C, when analyzed, gave as its constituents:—

Silica	50·50
Lime	13·07
Alumina	17·20
Protoxide of iron	10·10
Ditto manganese	2·24

Magnesia	5.04
Sulphuric acid . . .	·27
Phosphoric acid . . .	·15
	98·57

Pig-irons generally contain silicon, carbon, and calcium to a variable amount, along with small quantities of other ingredients. The causes for the presence of silicon are not very well understood. To the use of heated air an increase of it has been attributed; but on reviewing a large number of analyses of both hot and cold blasts, it seems doubtful if the former produces an important increase of this substance. In a large number of cold-blast irons, the silicon ranged from 0·33 to 2·80; while in similar analyses of hot-blast irons, its presence was detected in quantities varying from 0·38 to 3·00 per cent. The variation in the amount has also been explained by a chemical hypothesis; but the more probable cause of the reduction of flint or silicic acid to metallic silicon is inequality of temperature in the hearth, arising from the imperfect mode of applying the blast. The points supplied with an excess of air are heated sufficiently to reduce the silicon, though the average temperature of the hearth may be very low.

The quantity of carbon combined with the iron appears to be dependent on the fuel, and on the rapidity with which the charge descends, as well as on the character of the ore. In the preceding example, the gray contains rather more than the white iron; but the reverse of this sometimes occurs. As a rule, the colour of the "pig" affords no criterion of the quantity of carbon. With the same quantity, the iron may be either gray, mottled, or white. Ores of an open, porous description, such as the carbonates of the coal-measures and the carbonaceous ores of Scotland, are favourable to a high per-centage of carbon with the metal. The dense hæmatites and magnetic oxides, on the other hand, smelt into iron having a minimum per-centage of carbon. The production of gray iron from these ores requires that they be reduced to a small size, so as to increase the surface exposed to the action of the gaseous carbon. A rapid descent of the charge, which affords a shorter period for the action of the gases, appears to result in a diminished quantity of carbon in the iron.

Calcium appears to enter into the composition of nearly all pig-irons, and, from comparison, it seems less variable in amount than the other ingredients. A sample of cold-blast white iron, with a high yield of limestone flux, gave 0·95 per cent. of calcium; while a hot-blast white iron afforded only 0·20 per cent., being the smallest quantity observed. Although the presence of calcium demonstrates the existence of a slight affinity between that metal and iron, the great bulk of calcium passes into the slag as lime. The suggestion offered, respecting the variable amounts of silicon, applies also to the calcium in cast-irons;—namely, that it is reduced at intensely heated points of the hearth, while other parts may be comparatively cold.

The quantity of magnesia reduced to the metallic state of magnesium, and entering as such into the composition of pig-iron, is small; by comparison,

however, the portion reduced appears to bear nearly the same ratio to the quantity entering the furnace, as do the quantities of silicon and calcium, reduced from their respective oxides. Hence, its presence is probably due to the same causes.

Manganese, when present, appears to enter into the composition of crude irons to a larger extent than either of the foregoing substances. Most of the carbonates contain small quantities of manganese compounds, which appear to be partly reduced, the resulting manganese ultimately combining with the iron in the lower hearth. In the case of the analysis numbered B, the quantity of manganese is unusually large; a circumstance probably owing to the manganiferous iron ores of West Somerset being largely used at these works. The German crude irons smelted entirely from ores of this class, display a proportionately larger admixture of manganese up to 8 per cent.

The phosphorus of the ore appears to combine with the iron, passing, for the most part, into the crude cast-iron, but to a small extent into the cinder. It is commonly supposed that the entire quantity of phosphoric acid of the ore, is found in the crude iron. Analyses, however, demonstrate that this occurs only when the cinder is nearly devoid of that metal. The proportion which the quantity entering the cinder bears to the whole, is in the same ratio as the iron in the cinder is to the quantity of iron entering the furnace. Scouring cinders generally contain notable quantities of phosphorus, a circumstance attributable to their larger per-centage of iron. The quantity of phosphorus in hot-blast irons, is generally greater than in cold; but a satisfactory explanation of the cause has not appeared.

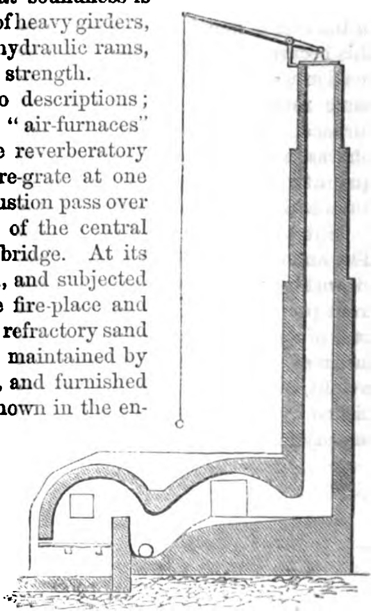
Sulphur forms a very general ingredient in the composition of crude iron. The amount varies with the quality of the fuel and ore, as also with the mode of working; being larger in hot than cold-blast irons, and largest of all in irons produced with a diminished depth of material in the furnace, as in the case of appliances for the utilizing the gaseous products. In some hot-blast furnaces, wrought on this system, the quantity forms nearly 2 per cent., by weight, of the iron. The sulphur may, in most cases, be considerably diminished by using an excess of lime. Common salt is an old and advantageous remedy for the same defect.

CHAPTER XI.

MOULDING AND FOUNDING.

THE crude iron of the blast-furnace is variously disposed of: the larger portion is applied to the manufacture of malleable iron, while the remainder is converted direct into innumerable articles formed of cast-iron. Occasionally, the smelter carries on the founding business also; in which case, castings are frequently made by running the molten iron direct from the blast-furnace into moulds. At other times, the crude iron is run into pigs or bars of convenient size, allowed to cool, and then charged into other furnaces for remelting. This plan affords facilities for examining the quality of each piece charged, and is followed whenever great soundness is required in the castings,—as in the case of heavy girders, beams, and framework of engines; for hydraulic rams, and similar works requiring undoubted strength.

The remelting furnaces are of two descriptions; technically, they are distinguished as "air-furnaces" and "cupolas." The former are large reverberatory furnaces, built of fire-brick, having a fire-grate at one end, from whence the products of combustion pass over the charge on to the flue. The floor of the central part is made sloping to the divisional bridge. At its highest part, the charge of pigs is laid, and subjected to the intense heat reflected from the fire-place and roof, until fused; when it flows over the refractory sand bottom to the hearth. The draught is maintained by a lofty chimney, bound with iron hoops, and furnished with a regulating damper at top, as shown in the engraving.

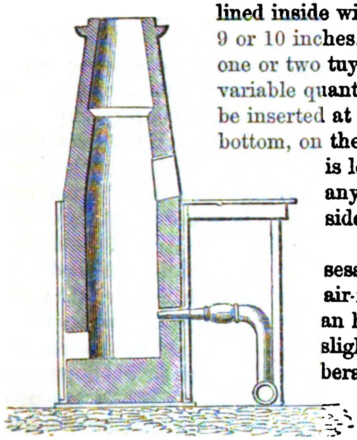


Founder's Air-furnace.

The dimensions of the furnaces are proportioned to the magnitude of the work generally performed in them, namely—from 3 to 10 tons at a casting; which is the common range of their capacity. Doors are provided on one side for charging the pig-iron and supplying the fuel; and on the opposite side is a smaller opening for tapping the molten iron into the foundry. In consequence of the intense heat to which the brickwork of the furnace is subjected, a system of strong plate and bolt binding is adopted to retain the erection in position.

The cupola is a blast-furnace of small size, in which the intense heat

necessary for fusion is maintained by a fan or other blast. The interior dimensions measure from 18 inches to 3 or 4 feet in diameter, and 6 to 10 or 12 feet in height. It is commonly made of iron plates, bolted together, and lined inside with the best fire-brick, to a thickness of 9 or 10 inches. The blast (cold) is supplied through one or two tuyeres, which, for facility of operating on variable quantities of iron, are so made that they can be inserted at different heights of the furnace. At the bottom, on the side adjoining the foundry, an opening is left for tapping the metal and removing any cinder or other matter adhering to the sides.



Founder's Cupola Furnace.

Each of these remelting furnaces possesses certain advantages of its own. The air-furnace is preferred where toughness and an homogeneous structure are required; the slight decarbonating influence of the reverberating column of carbonic acid and other products of combustion from the fire-place, appears favourable to a retention of strength. The iron so treated can be filed and chipped, and otherwise cut to shape, with great facility. It contracts less, and with greater regularity, than iron otherwise treated.

Cupolas are less expensive to erect where a supply of blast can be obtained cheaply; and for many operations are extremely useful. Small quantities of iron may be advantageously fused, and by means of ladles conveyed simultaneously to several parts of the foundry. Castings from cupolas, however, are weaker, and less to be depended on, than those from air-furnaces. In consequence, also, of the carbonizing action of the blast on the metal in the furnace, the castings produced are generally very hard, difficult to cut, and disposed to fly (break spontaneously, through unequal contraction) whilst cooling; and even afterwards, danger is to be apprehended from sudden changes of temperature. The tensile strength is inferior, and probably arises from partial disruption of the cohesion, through unequal contraction in cooling.

By the founder, iron castings are distinguished as open sand, green sand, dry sand, loam, or chilled castings, according to the mode of moulding. Occasionally a complex piece embraces two, or even all five methods. The *open sand* method is adapted for rough articles, such as flooring-plates, and other castings in which one side is permitted to be uneven. *Green sand moulding* is largely practised in the production of stove fronts, pans, small pipes, and the innumerable small articles of commerce, plain and ornamented, of cast-iron. *Dry sand* is applied to large pipes, engine and mill-work, to girders, and other large castings requiring great strength. *Loam* is a modification of the dry sand method, and is principally applied to large circular castings, such as cylinders and wheels. *Chilled castings* are those cast in

thick iron moulds instead of sand: the surface of the metal in contact with the cold iron is rendered extremely hard, in consequence of the sudden manner in which it is cooled. It is much used for axle-boxes, rollers for coffee and sugar-mills, and all purposes requiring great hardness, and capacity for resisting abrasion.

Open Sand Moulding.—Moulding in open sand is the simplest mode, and requires comparatively little skill. An exact model of the intended casting is made in white deal wood, and placed in an excavation in the damp sand floor of the moulding-bed, the top level with the floor line. Having carefully levelled the model with a T level, the moulder proceeds to ram the sand tightly round it in small quantities at a time, with the large end of a tamping-bar. The sand, placed in contact with the model, is selected with care, and sifted to separate any particles of iron. On attaining the level of the model, the tamping is discontinued, and the sand at the top carefully smoothed with a small trowel; to strengthen the edges in contact with the model, a few drops of water are sprinkled over the sand. With a large iron wire, curved so as to pass under the model without touching it, the moulder pierces the sand all around several times; the model is now taken out, for which purpose an iron spike is screwed into the top, and repeatedly struck lightly, to loosen it from the sand, when the moulder carefully draws it up. To facilitate its removal, it is made rather larger above than beneath, and the adhesion of sand partially prevented by singeing the surface of the wood. In the event of any portion of the sand having been detached in the act of removing the model, the damage is repaired with a little fine sand, worked with the trowel. The interior is then dusted over with some burnt sand from previous castings, or charcoal dust sifted through a horse-hair sieve. If very deep for an open sand casting, the edges of the mould are prevented from rising by a series of heavy weights, disposed wherever there is space. Shallow castings have the edges of the mould protected by thin plates: in all cases care is taken, by weights or sprigs, that the pressure of the molten metal shall not lift up the sand wall. From the top of the mould, previous to withdrawing the model, a small canal is made in the sand-bed leading to the smelting-furnace, or to a small pit, into which the metal is poured from a ladle. The communication with the mould is closed by a small iron gate-plate, loamed over to prevent the adhesion of the iron until casting time. If the casting be deep, the canal is continued to the bottom of the model by a small bore-hole, at a few inches' distance from the body of the intended casting. Large castings require two or more branches to the canal, to convey the iron to different parts of the mould simultaneously.

The filling of the mould demands great attention, and requires to be done as rapidly as may be practicable. If the metal is run direct from a furnace, it is brought simultaneously to the several gates, and allowed to flow into the different parts of the mould in nearly the same volume. The sprinkling of a few drops of metal around the air-holes left by the wire produces a slight explosion, through ignition of the inflammable gases arising from them. These continue to burn so long as the outside of the metal possesses the

property of decomposing water. The molten iron is carefully skimmed from time to time, and any oxidized matter removed from the surface. If, at the termination of the running, the mould appears to be filling unequally, the defect is remedied by the adjacent stop-gates being opened or shut, as the circumstance may require. The molten iron is never poured direct from a vessel into the mould; but in a mould partly filled, it is sometimes allowed to flow direct from the ladle. The running finished, the surface of the metal is usually sprinkled with a little dry sand, and the casting left in its bed until sufficiently cold for removal.

If soundness is required, no casting of any kind should be removed until cooled down throughout, to within a few degrees of the atmosphere; and in the case of open-run castings, a thick covering of sand should be applied to retain the heat. If removed too soon after casting, the piece is irreparably weakened, if not fractured and lost. Want of room in a confined foundry is commonly adduced as a reason for turning out the work as soon as it has solidified; but a desire to turn out more work than the foundry is capable of producing, is perhaps nearer the mark. From whatever cause it may arise, it is too evident that many disastrous accidents have arisen from the breakage of girders and mill machinery, resulting solely from inattention to this point; thus occasioning great mistrust in cast-iron as a material of construction, and lowering its commercial value.

Green Sand Castings differ from open sand, in being covered with the half of a box during the process of casting.

The green sand of the founder is an argillaceous sand, in the state in which it is raised from the gravel-pit, having been first sifted through a fine wire sieve, carefully mixed with about one-twelfth of its volume of finely powdered coal, and slightly moistened with water; in this state it retains the exact form of any object impressed on it. This mixture can only be used once for the formation of moulds, being afterwards employed for filling up. In order to obtain the form of the pattern, the moulder takes a cast-iron frame, which is filled with sand and closely rammed. Taking the pattern from which the casting is to be made, the workman scratches on the smooth surface of the sand, and in the centre of the iron frame, a rough resemblance of the model, which is embedded into the sand to one-half its thickness; it is then sprinkled over with charcoal dust.

A counterpart of the cast-iron frame is now filled in a similar manner with sand closely packed, dusted over, also, with charcoal dust, and placed upon the model; by this process a mould of the other half is impressed upon it, the charcoal dust preventing any adhesion between the two parts of the frame. The upper frame is now carefully raised, and the model removed from the lower frame, any slight imperfection in the mould being repaired by the use of a little moistened sand, and a small trowel shaped for the purpose. The two parts of the frame are now joined together by means of corresponding pins and holes, and a cavity remains of the form of the required casting.

Small articles also have a bottom box; and if of a complex form, may require several boxes for their complete formation. Pulleys, for instance,

require a three-part box—a top, middle, and bottom. The moulding boxes, whether for green or dry sand, are made of cast-iron, with cross ribs, wherever the nature of the model permits, for holding the damped sand. The separate parts are made to fit each other accurately by taper pins, through which keys are driven to bind the several parts firmly together during the operations of moulding and casting. If the several parts of the box are large, requiring the assistance of a crane for handling, each part is furnished with trunnions, on which it is turned over, and its under side dressed up by the moulder. The filling of the mould is conducted in much the same manner as with open castings; a suitable jet being left for the escape of confined air.

The moulding of pulleys, as requiring a three-part box, very well exemplifies the principles of the art. The model of the pulley, a section of which is seen in Fig. 1, is made in two halves, fitting each other with suitable drilling pins. If several are to be cast from the same model, a cast-iron one is commonly made from a wood pattern, and subsequently fitted to remove any asperi-

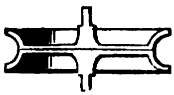


Fig. 1.

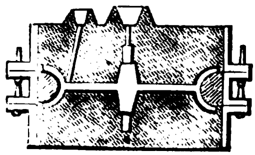


Fig. 2.

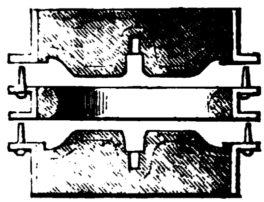


Fig. 3.

Pulley Moulds.

ties on the surface. In the bottom part of the box the lower side of one half of the model is moulded; all superfluous sand removed, the exposed portions carefully smoothed over, and fine charcoal dusted over it. The upper half of the model is fitted on, and the middle part of the box clamped down. In this portion of the box the hollow edge of the pulley is moulded, as may be seen by reference to Fig. 3, where the three parts of the box, when moulded, are shown, drawn slightly asunder. The sand is again smoothed down, and the surface dusted preparatory to re-covering the top part of the box. This is placed on the middle part, and the upper side of the pulley moulded in it. Having left an orifice for the entrance of the metal, and another for the escape of the air, the top part is lifted off, with the upper half of the model adhering to it. The middle part is next lifted off; this, it is seen, is a mere ring of sand, filling up the hollow periphery of the pulley. After removing the halves of the model, the parts of the box are replaced, preparatory to casting, as shown in Fig. 2. The charcoal dust prevents the sand in one part from adhering to that in the others.

Dry Sand Castings are usually prepared in boxes similar to those used by green sand moulders. This is more especially needful where a great weight of metal is to be cast in moulds made of this material. Dry sand is generally used without any admixture of coal-dust. Castings made in this material are less liable to imperfections and air-holes, than those prepared in ordinary green sand moulds, its porous nature permitting of a freer escape of the gases,

while there is less chance of its chilling in the mould from the baking process which it undergoes before introducing the metal.

In all casting processes, much of the success of the operation depends on the skilful manipulation of the moulder; on him must depend the adjustment of the mould, and the weight of the metal with which it is charged, the due admixture of the materials, with that degree of porousness necessary for the escape of the gases as they are generated by the fluid metal.

When complete, the several parts of the box are taken separately to a large oven, or drying-stove, and thoroughly dried, to expel all moisture from the sand. Afterwards the interior of the mould is blackened with thick washes of ground charcoal, or coke, worked up with water to a proper consistence. It is again dried, and the several parts adjusted to each other. If the box seems to require strengthening before the performance of casting, it is sunk in the sand, level with the floor of the foundry; and on the upper part are laid several heavy weights, supplemental to the side keys, in keeping the structure rigidly together under the pressure of the liquid iron.

Several peculiar configurations of cast-iron, also such holes as may be required in the castings, whether large or small, are formed with cores, or loose pieces of sand, strengthened wherever necessary by internal iron bars and frames. These cores are made by tightly ramming the best sand, in iron or wooden boxes of the required shape, and then placing them in the stove to dry; subsequently they are blackened, and treated as the other parts of the mould. By means of a system of hollow and solid cores, all castings, whatever be their configuration, may be made with comparative facility; and not unfrequently pieces, the construction of which would seem to involve difficulties, are made with only a few core-boxes and a plain model.

Loam Moulding differs from the other methods, inasmuch as no models, or core-boxes, are used; but the moulds are made directly from drawings of the objects to be produced. The mould is made of a mixture of clay, water, sand, and cow-hair, which is first reduced to a paste, and thoroughly kneaded in a pug-mill. This mass is made to assume the required form by the use of various instruments; the proportions of the various ingredients being changed to suit different purposes. The preparation of the loam mould is frequently a difficult process, requiring a skilful moulder, as he is sometimes required to shape and mould very complicated forms with only his eye to regulate his tools. The profile of the circumference of the required casting is cut on a stout board, and attached at the requisite radius to a rigid iron spindle, which freely turns, vertically, on suitable bearings. The mould for a large cylinder, for instance, is commenced at the bottom of a dry pit in the foundry, by laying a course of brick-ends on the loamed bottom to the reach of the sweep-board, and covering their upper surface and face with a layer of loam (sand worked up to the consistence of thin mortar, strengthened by some weak fibrous substance). The board is now swept around, removing any superfluous loam, and a second course of bricks laid on the first; loam is added; and in this manner a rough wall of the required height is built. The inside is well plastered with loam, which is wrought to the precise form

by sweeping around the board, and finished with a coat of fine material. When the outside of the mould is complete, the board is taken out, and a grate with lighted fire suspended in it, to effect a thorough drying; subsequently it is blackened, and again dried. The core is built in a similar manner, on a circular platform of the required size, which revolves while being built against a fixed loam-board.

Cores for pipes and smaller cylinders are built around a hollow cylindrical core-bar, pierced with numerous holes and open at the ends, with the exception of the space occupied by the trunnions. Around this cylindrical bar is laid a covering of hay or straw rope, and then the usual coating of

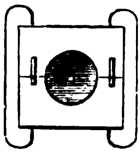
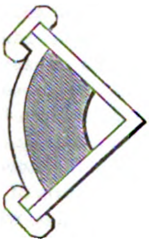
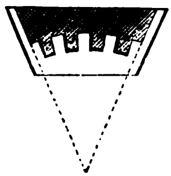


Fig. 2.





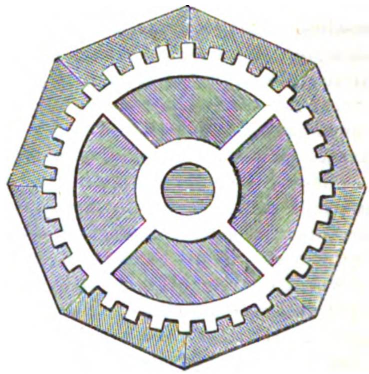


Fig. 1. Fig. 3. Fig. 4.

Tooth-wheel Moulding.

loam, drying and blackening. The gases generated in the casing of the core-bar escape through the small holes into the hollow cavity of the core-bar, and out at the ends where they are ignited. The hay-bands freely allow of the pipe contracting in cooling, which it could not do around a solid substance, and permit of the ready withdrawal of the bar.

The moulding of a large tooth-wheel may be taken as an illustration of the manner in which castings, partly in loam and partly in dry sand, are worked up. The moulding of a wheel with four arms (Fig. 4) is accomplished by loaming a level surface in the wheel-pit, and arranging, by means of a trammel working from the centre, a number of tooth-cores made in the core box (Fig. 3). The model teeth in this box are usually loose, and kept in their place by passing through mortices in each side; the two sides are kept together while tamping by clamps. Four arms are formed by the same number of moulds (Fig. 1), while a third box (Fig. 2) forms the centre core. Great accuracy is required in the setting of the cores; and allowance has to be made for contraction of metal in cooling.

An inspection of the figures will convey a correct idea of the way in which many moulds are built up at comparatively trifling expense; and it is to be borne in mind that the binding together of the several parts of the boxes and

frames, by means of the taper-pins and cross-keys, previous to pouring in the molten metal, is an operation requiring great care on the part of the operator.

Liquid cast-iron presses with a force exceeding one pound the square inch when the column is four inches high. Castings are frequently made and cast, with a column of liquid iron ten feet high; in which case, every inch of the mould exposed to this column has to resist a bursting pressure of more than thirty pounds, or about one-half the pressure to which high-pressure steam-boilers are subjected. Under such circumstances the boxes require to be of great strength, perfectly rigid, and bound together at short intervals with heavy iron bands, in addition to the pins and keys. In green-sand moulding, the column of metal is usually much less; but the surface extended horizontally, demands nearly the same precautionary measures.

CHAPTER XII.

THE STRENGTH AND OTHER PROPERTIES OF CAST-IRON.

THE properties of iron of greatest importance in construction and mechanical engineering are — 1. tenacity; 2. transverse strength; 3. power to resist impact; 4. power to resist fatigue; and 5. power to resist compressing or crushing forces: to these must be added, in the case of the founder and turner—5. fluidity; 6. hardness; and 7. texture. For special purposes, other qualities are sometimes sought after, but the foregoing comprise the essentials required in a good cast-iron.

It is well known to founders and mechanical engineers, that the several qualities for which a given cast-iron may be distinguished, are susceptible of considerable modification, improvement, and more marked development, by special treatment in the hands of the founder; and to smelters, that the general qualities of the original crude pig-iron are dependent, in great measure, on the chemical composition of the ores, fuels, and fluxes, and in the smelting-furnace: but with similar materials, the method of working the furnace, the temperature of the blast, the construction of the furnace itself, and various other causes, are found to exercise important influences. The crude iron of the blast-furnace, however, is rarely used for the formation of valuable castings, until it has undergone one or more remeltings; and the following remarks will apply only to iron which has been reworked in this manner.

The importance to the engineering profession, and to science generally, of an elaborate series of experiments on the qualities of cast-iron, has been very generally felt for the last quarter of a century; but the time required for their prosecution, and the expense necessarily involved, have been too great for any private individual. Several engineering firms have made a few experiments on the metal as preliminary trials, previous to the execution of particular works; and the British Association for the Advancement of Science allotted a small sum of money for some limited experiments on form and application. More recently a commission was issued by Government to inquire into the application of iron to railway structures; but its labours were confined to testing the stability of a few railway bridges, and collecting the verbal opinions of engineers as to the merits of particular brands of pig-iron: the results of the inquiry were of little or no value to practical workers in the metal.

In the United States, the great difference observed in the strength and durability of cast-iron ordnance, apparently composed of equally good metal, led to the adoption of measures for ascertaining the cause of such difference. These measures were first applied about thirteen years since, and conducted out of the public revenue of the States by competent and highly painstaking officers of engineers: the results as published form the most complete and

reliable record of experimental researches on the metal yet issued in any country; and contrasts most favourably with the manner in which similar researches are undertaken and conducted in England. From this work, and from private researches, will be collected, in a condensed form, a few of the principal known facts relating to the qualities of cast-iron.

Tensile Strength of Cast-iron.

In all purposes to which cast-iron is applied, tenacity is a quality of the first, if not of paramount importance. Transverse strength, the next in the order of importance, is directly dependent on the tenacity of the metal. Hence, in all well-conducted researches into the qualities of pig-iron, tenacity takes precedence of the others. It is influenced by several causes, separately and combined; the chief of these, so far as yet ascertained, is—

Temperature of the Blast used in the Reduction of Cast-iron.

With the invention and application of the hot-blast, there arose a very general belief that the new process tended to largely deteriorate the tensile strength of the pig-iron produced. With the existing furnaces, however, the invention in one district effected such a considerable saving of coal in the furnace, that the generally inferior character of the iron prepared with it was controverted by the manufacturers. And at the present day the inferiority is very frequently ascribed by writers to the facilities which this invention affords of working up materials of a quality inferior to those capable of being reduced by a cold blast. Recent researches, however, have demonstrated, that with similar ores, fuel, and flux, the quality of hot-blast iron is greatly inferior to that of iron smelted with a cold blast.

The experiments made for the British Association, with a view of settling this point, were the first of their kind publicly undertaken; and the results are subjoined:—

		Tenacity in lbs. per sq. in.
Carron No. 2 quality pig-iron	hot blast	13,505
" do. do.	cold "	16,683
" No. 3 quality pig-iron	hot "	17,755
" do. do.	cold "	14,200
Coed Talon No. 2 quality pig-iron . .	hot "	16,676
" do. do.	cold "	18,855
Bufferey No. 1 quality pig-iron . . .	hot "	13,434
" do. do.	cold "	17,466

The number of pig-irons tested was sixteen; and it will be observed that, with one exception, the cold-blast irons are greatly superior to the hot. The single exceptional case led the experimenters to the conclusion, that the lower qualities of iron were improved by the use of hot air to nearly the same extent as the higher qualities were deteriorated. This conclusion, however, was founded on a single experiment; and to have been of any value, a fresh por-

tion of iron should have been taken, and experimented on for corroboration of such a striking anomaly.

Previous to these experiments, the Low Moor Company—whose works in the Bradford district, well known for the superior quality of the iron produced in it, had been wrought entirely with cold blast—adopted the new mode of smelting; but the reduction in quality was such, that the cold blast was resumed after a very brief trial. These and the other works in this district have since continued to use a cold blast only. Experiments were made on the Low Moor irons as prepared by the two processes, and the following results obtained, the strength of cold-blast iron being taken as unity:—

Mean breaking weight of cold-blast pig-iron . . .	1·000
Do. do. hot do. . . .	·831

Subsequently experiments were made at the Dowlais Works on irons remelted in an air-furnace, also on others remelted in the cupola, with results nearly the same as those occurring at Low Moor: the relative strengths being:—

Mean breaking weight of five bars of cold-blast iron	1·000
Do. do. six bars of hot-blast iron	·835

The discovery that a cold blast of sufficient density could be successfully used in forcing furnaces using anthracite fuel, resulted in some comparative trials being made at the Ystalyfera works on irons prepared by the two processes. The result of a large number of experiments tended to establish the fact of a large deterioration occurring with the hot-blast irons: the relative strengths of the two irons being—

Anthracite iron, cold blast	1·000
Do. do. hot blast	·802

These experiments, made on irons reduced from similar ores and under circumstances precisely equal, temperature of blast excepted, must be held conclusive as far as regards the irons of this country. The experiments in the United States were made principally on charcoal irons; nevertheless the results are even more unfavourable to the hot-blast irons. The diminution of tenacity which follows on the heating of the blast, is shown in the following statement of the effects produced on the American furnace iron:—

	Tensile strength in lbs. per sq. in.
Blast cold	14140
Do. heated to 150°	12243
Do. do. 200°	12970
Do. do. 250°	11420

This pig-iron was of No. 1 quality, and cast, for the purpose of experiment, into bars in the open-sand furnace-bed. The difference in the tensile strength of hot and cold-blast iron from the same furnace was so great in several instances, that the officers engaged in the inquiry sought and obtained

the most ample proof, that in every case the inferior metal had been produced from hot-blast iron. In the case of seventeen guns cast from hot blast, eight failed to stand the proof. Experiments on the metal in three guns gave a density of 7·09, and a tenacity of 20,732 lbs. to the square inch. Similar experiments on guns cast at the same works several years previously, but from cold-blast iron, gave a density of 7·185, and a tenacity of 25,246 lbs. to the square inch.

It is worthy of remark, also, as bearing out the opinion that the quality of our pig-iron has deteriorated within the last half century, that in an English gun imported into America in 1815 the cast-iron was of a density of 7·04, and tensile strength of 18,145 lbs. to the square inch; while other English guns imported about thirty years previously contained metal of a density of 7·202, and tensile strength corresponding to 28,067 lbs. to the square inch.

The analyses made in the laboratory attached to the Pikesville Arsenal are singularly confirmatory of the unfavourable opinion respecting the hot-blast current, soon after its introduction. The results of numerous analyses, on irons prepared by the two processes, gave—

	Cold blast.	Hot blast.
Specific gravity	7·194	7·074
Tensile strength	26,859	18,993
Combined carbon	·0836	·0687
Graphite	·0476	·0600
Silicium	·0386	·0593
Slag	·0189	·0375
Phosphorus	·0228	·0185
Sulphur	·0014	·0010
Manganese	·1141	·0960
Earths	·0117	·0146
Silicium and carbon	·1210	·1281
Silicium and slag	·0575	·0938
Graphite and slag	·0665	·0975
Graphite, slag, and silicium	·1051	·1568
Graphite, slag, silicium, and phosphorus	·1280	·1753
Total carbon	·1312	·1287
Graphite, slag, silicium, phosphorus, sulphur, and earths	·1411	·1909

The result of the numerous experiments made in the United States on cast-irons has been the entire rejection of hot-blast smelted iron as a material for constructing ordnance. It must not, however, be supposed that hot-blast iron is inapplicable, or inferior to cold-blast irons, for all purposes. Where great tensile strength is desired it should be carefully avoided; but under other circumstances, it may frequently be substituted for cold-blast iron with considerable advantage.

Remelting the crude iron has an important influence on its tensile properties. An improvement in quality is very generally observed on remelting the crude pig-iron of the blast-furnace in reverberatory furnaces. With founders this improvement is ascribed to the more homogeneous character of the iron so treated, over that of the original pig; but the author, in his large work, combated this opinion, and placed it to the credit of the refining of the iron which necessarily takes place at each remelting. The publication of the American experiments confirms this view of a mere remelting resulting in the production of a more pure metal.

Crude pig-iron of the blast-furnace was taken and thrice remelted to observe the change of quality and increase of density produced; the results were:—

	Density.	Tensile strength in lbs. per sq. in.
Crude pig-iron	6·974	14,000
Do. remelted once	7·090	20,900
Do. do. twice	7·229	30,229
Do. do. three times	7·301	35,786

In a second series of experiments the improvement in quality, by remelting, was equally marked. The metal operated on was cold-blast charcoal pig-iron, cast in similar moulds and under similar conditions, the number of fusions alone excepted:—

	Tensile strength in lbs. per sq. in.	Density.
Crude pig-iron	11,020	6·949
Do. do. remelted	15,942	7·069
Do. do. remelted twice	35,846	7·327

In another case, the iron of third fusion attained a density of 7·304, and tensile strength of 45·970 pounds per square inch—the highest ever sustained by cast-iron.

Experiments on a limited scale were made for the British Association by Mr. Fairbairn; and the results, though less marked than in the American experiments, demonstrate the great advantages which may, in many instances, be derived from a mere remelting of the cast-iron.

One ton of Eglinton hot-blast iron was operated on, and the proportion of flux and coke at each fusion accurately measured, so as to be alike at each. The iron was run into bars one inch square, and the trials were made on lengths of about four feet, supported at each end, and the weight applied in the centre gradually, until the bar broke: one bar was reserved at each trial, and the rest of the iron again remelted. This succession of remeltings and trials was repeated seventeen times, when the quantity of iron was too much reduced for a continuance of the experiments. The results obtained prove that cast-iron increases in strength up to the twelfth melting, and that it then rapidly deteriorates. The commencing breaking-weight was 403 lbs., and this went on increasing until at the twelfth melting the breaking-weight was

725 lbs. At the thirteenth it was 671 lbs.; at the fifteenth 391 lbs.; at the sixteenth 363 lbs.; and at the seventeenth melting the ultimate strength was 330 lbs.; or less than one-half of its maximum strength. After the fourteenth melting, the molecules of the metal, when fractured, appeared to have undergone a decided change. There was a bright band, like silver, on the edge of the bar, whilst the middle retained the ordinary crystalline fracture; and in the succeeding meltings, the metal was bright all over, resembling the fracture of cast steel.

Maintaining the iron in fusion for shorter or longer periods, is attended, in many instances, with a corresponding improvement in the textile strength of the product. By keeping it in fusion a longer period, the number of remeltings necessary to develop its maximum strength may be reduced. In the case of the Manchester experiments referred to, the iron was in comparatively small quantity, reduction to a molten state took place with great rapidity, and the process was completed in a very short period. The American experiments, on the other hand, were made on several tons of iron, in reverberatory furnaces; reduction to the liquid state took place more slowly, and the entire process lasted several hours. The gradual reduction, also, of the iron and its flowing to the hearth, exposed it to a prolonged decarbonization, and resulted in a corresponding greater purity, with fewer remeltings.

The improvement in quality obtained by keeping the iron in fusion for periods after reduction, is very well shown by the results obtained with the Stockbridge iron:—

	Tensile strength in lbs. per sq. in.	Density.
Iron twice remelted and cast on reduction to liquidity	15,861	7·196
Do. maintained in fusion 1 hour	20,420	7·234
Do. do. do. 2 "	24,383	7·270
Do. do. do. 3 "	25,773	7·283

In other experiments the increase of density and tensile strength is equally great, and shows the wide field for improvement which the mere difference in mode of reduction and time of casting offers to the consideration of the practical founder.

	Tenacity.	Density.
Iron in fusion ½ hour	17,843	7·187
Do. do. 1 "	20,127	7·217
Do. do. 1½ "	24,387	7·250
Do. do. 2 "	34,406	7·279

The several trials were made with the same charge of iron, but the metal for testing was withdrawn at the periods named. The composition of the original gray pig-iron doubtless influences, in a very great measure, the amount of improvement obtained with different periods of fusion. A refining of the iron takes place; and the quantity of alloyed matters oxidized and removed, will vary with the character of the pig-iron. Carbon is a principal

ingredient in cast-iron; and a long exposure, equally with repeated meltings, offers a ready method of burning it away. The reverberating column of gases in the remelting furnace, contains a proportion of free oxygen, which combines with the carbon to form carbonic acid; but since the oxygen is in contact only with the surface of the metal, its removal requires numerous fusions, or the maintenance in fusion for a long period. Repeated fusions of the iron are attended with a heavy waste of material, which goes far to compensate for the increase of strength. In the experiments at Manchester, the maximum strength was obtained only at the twelfth fusion, and then exceeded the original strength in the ratio of 725 to 403. This increase, however, was obtained by a waste in remelting of more than one-half of the iron originally charged; so that, in a commercial point of view, a casting of given strength prepared from iron remelted this number of times, will cost nearly twice as much as a similar casting prepared from the original crude iron.

By exposing the molten iron to the white-hot current of gases for a longer period, the improvement in strength is obtained with a comparatively small waste of material. Apparently, the forcing of air under the surface of the iron, so as to pervade the entire contents of the hearth, and react with great rapidity on the alloyed matters, would accomplish the refining and development of strength most completely; but in practice the reverse is found to follow this treatment. Combustion of a portion of the iron takes place; and the newly-formed oxide, remaining to a certain extent amongst the particles of iron, reduces its tenacity below that of the original crude iron. On the other hand, the exposure of the reduced iron to a current containing free oxygen results in the rapid deprivation of carbon, silicon, phosphorus, sulphur, &c.; the first in a gaseous combination, the rest in the slag produced in the process. The temperature of the molten mass in the hearth is unequal, and subject to slight variations; the result is the production of numerous slow currents, which successively bring the entire charge of metal under the refining influence of the passing current of gases.

Irons containing a large proportion of carbon, relatively to the other impurities, are most susceptible of improvement by treating in this manner. With other irons, prepared with a heavy burden of materials on the blast-furnace, the improvement is less striking, and is attended with a larger waste of metal through oxidation.

The rapidity and manner of cooling the casting, directly influences the tensile strength of the metal. It is found that small castings, moulded in vertical dry-sand flasks, have a less tensile strength than large castings similarly moulded, and cast from the same charge of iron. The diminution of strength in the case of the small bars amounted to nearly five per cent. Tested transversely, however, the strength of the metal in the small casting was to that of the metal in the large as 1145 to 1000. This difference between the comparative tensile and transverse strengths of the iron from the two castings is easily explained. The rapid cooling of the small bar resulted in the skin attaining great hardness, and the metal to be in a state of tension. This, while it increased the transverse strength, reduced the ability of the

iron to bear a direct tensile force. The large casting cooled slowly, in consequence of its great bulk; and the heat in the interior mass having to pass through the skin, produced a partial annealing of this portion. Softened in this manner, it was less able to bear a transverse strain; but the equal rate of contraction of the mass was favourable to the resistance of tensile force.

The tensile strength, as influenced by the size of the masses and rapidity of cooling, varies with the condition of the iron previous to casting. If the refining process, by lengthened fusion or numerous remeltings, be carried too far, the resulting product will be of a hard, brittle quality; and when cast into small articles, be chilled to that extent as to be incapable of working with steel cutting-tools. Cast into larger articles, however, and cooled more slowly, a maximum tenacity may be developed, and the texture of the iron be found of a character to bear cutting-tools on its surface.

Continuing the operation too long, also produces a thickening of the molten iron, until it is of too great a consistence for the proper filling of the moulds, and the prevention of air cavities in the body of the casting. The burning away of the carbon is attended with a loss of fluidity; and this defect occurring, there is no remedy short of introducing further portions of the original crude iron, to restore by mixing a certain degree of fluidity. Thin castings, and others requiring great sharpness in the angles, can be successfully made only when the iron contains a large portion of the carbon contracted in the blast-furnace. Freedom from air cavities demands the employment of a similar metal.

Casting under a head, or considerable pressure of the fluid metal, is resorted to in very many instances, in order to obtain great solidity. The density of the metal is increased, attended with a corresponding augmentation of tensile strength. An experiment on the comparative density and tenacity of rough pigs cast horizontally, and a moulded bar cast vertically, gave the following results:—

	Tenacity.	Density.
Rough pigs, cast horizontally . . .	14481 . .	7·004
Bar, cast vertically	16424 . .	7·085

In all close-flask castings the head of metal is required to be several inches above the highest point of the mould, or the perfect filling may not be ensured. Rollers for mill machinery, and numerous other articles, are frequently cast with a vertical pressure of two or three feet of liquid metal above the most elevated part of the mould. The effects of atmospheric pressure on the surface of the liquid iron, while cooling, has been tried, and apparently produced a small improvement in the metal. Further experiments, however, are required to show the amount of each improvement under varying pressures of blast.

By the rapid cooling of castings through the intervention of water, the tensile strength of the metal may be nearly destroyed. The unequal rates of contraction which ensue, bring into play forces greater than the cohesive power of the metal is able to withstand. A similar result is frequently ob-

served in the case of iron cylinders, cast in thick iron moulds, with the view of hardening the surface of the casting; especially if the metal is of a high quality. Fissures running nearly parallel with the axis of the cylinder are produced on its surface, and penetrate a short distance towards the centre. Their production is a result of the rapid cooling of the skin of the casting, through the absorption of caloric by the mass of cold iron composing the mould. With a slow and gradual cooling of the entire mass, the skin contracts equally with the rest; but in chilled castings it diminishes in diámeter more rapidly than the interior of the incandescent iron, which is forced out of the mould through the head while yet effectively liquid; but immediately solidification commences in the interior, the skin is in a state of tension, and, at its then temperature, a direct severance in one or more places is inevitable. This fracturing of the skin occurs only with irons possessing more than ordinary hardness previous to fusion; but it is only with such that an extremely hard surface to the cylinder can be obtained. Hence, the greater the degree of hardness imparted to the iron, the greater the liability to rupture in cooling.

These considerations point to the important bearing which the manner of cooling has on the tensile strength of cast-iron. The circumstance that a very rapid cooling is frequently attended with a direct fracture of the metal, before the casting has left the foundry, shows the very great attention which should be paid to this feature of the process. Unless great care be taken, the best pig-irons may be so weakened during cooling as to possess, in the finished casting, a tensile strength greatly below that of very inferior irons in other castings cooled on correct principles. Probably in a majority of castings, the quantity of the original pig-iron has less to do with the ultimate strength of the piece, than the mode in which the iron is treated during and after fusion.

When cast into large masses and slowly cooled, some time elapses before the molecules of the metal arrange themselves into the position offering the greatest resistance to tensile strain. The experiments made were confined to the testing, by repeated firing, of heavy ordnance, with various intervals of time between their manufacture and use. Pieces cast some years before testing, stood several times the quantity of firing of other pieces cast but a few months previously. The tensile properties of the metal did not explain the difference; and the form, dimensions, weight, method of casting and cooling, and the manner of proving, were the same in all the pieces tried. Further experiments on this remarkable property, are required to show the several circumstances under which it is developed.

The tensile strength of many cast-irons may be improved by adding to them, after fusion, but previous to flowing out of the remelting furnace, a quantity of wrought-iron in a divided state. By this proceeding the strength of the iron may be increased to nearly fifty per-cent. over that of the original pig. Since, however, the numerous experiments made in America have conclusively shown, that remelting alone will produce a much greater improvement of quality, we must infer that the increase of quality placed to the use

of malleable scrap really occurred from the remelting; and that by treating the iron to a prolonged fusion, greater strength would have been produced without the use of the scrap-iron.

Resistance of Cast-iron to Compression.

The force required to crush cylinders two and a half times their length, increases with the hardness of the iron, when the cooling has not permanently injured the structure of the iron.

No. 1 foundry iron required a force of			119,650 lbs.	the sq.	in.
Nos. 1 and 3 mixed	do.	do.	168,589	,,	,,
Nos. 1 and 2 mixed	do.	do.	152,560	,,	,,
Nos. 1, 2 and 3 mixed	do.	do.	160,803	,,	,,

In building, and construction, the direct crushing force is seldom brought into action to that extent that the metal is crushed to pieces. Accidents invariably occur from the lateral flexure of castings, produced through a deficiency of stiffness in the deflective part.

In order that the various qualities of different metals may be readily compared, and that the variations which occur in each may be seen at one view, results—collected from the preceding tables, and from all the forms in which the several metals were tested—are given in the following table:—

VARIOUS QUALITIES OF DIFFERENT METALS.

		Density	Tenacity.	Ultimate torsion.	Compres. strength.	Hardness.
Cast-iron	Least . .	6·900	9000	5605	84529	4·57
	Greatest . .	7·400	45970	10467	174120	33·51
Wrought-iron	Least . .	7·704	38027	..	40000	10·45
	Greatest . .	7·858	74592	7700	127720	12·14
Bronze	Least . .	7·978	17698	5511	..	4·57
	Greatest . .	8.953	56786	..	..	5·94
Cast-steel	Least . .	7.729	...	..	198944	..
	Greatest . .	7.862	128000	..	391985	..

This table shows the great range in quality of the cast-iron, wrought-iron, bronze, and steel operated on. By judicious treatment the tensile strength of the cast-iron is increased so as to be in excess of much of the wrought-iron manufactured, and nearly two-thirds of the strength of the best merchant bar-iron. With cast metal of this quality, the manufacture of malleable iron ordnance will no longer be a desideratum.

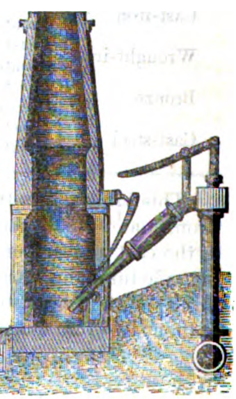
CHAPTER XIII.

MANUFACTURE OF WROUGHT-IRON.

THE conversion of the crude cast-iron of the high-blast furnace into the malleable iron of commerce, is essentially a succession of refining operations for the separation of the extraneous matters combined with the metal. The manner in which this is accomplished varies in different districts, and is, in part, influenced by the nature of the alloyed matter. The old, and hitherto preferable, process consists in exposing the molten metal to currents of blast for two or three hours, in a low open blast-furnace, technically termed a "refinery." In many works, reverberatory furnaces are employed, and the crude metal is exposed on the central bed to the action of a highly-heated column of gas from the fire-place, for about an hour and a half. Several of the French and American manufacturers employ the open charcoal forge, similar in construction to the Catalan hearth already described. It may be remarked, however, that whatever construction of furnace be employed for the purpose, atmospheric air is the principal agent employed in purifying the crude iron.

The Blast Refining Furnace

Is built near the blast-furnace, from whence the liquid iron flows direct into the hearth of the fire. It consists of a cast-iron framework, surmounted by a brick chimney; at the bottom is a shallow, quadrangular hearth, into which dip the tuyeres of two or more blast-pipes. The sides of the hearth are formed of hollow cast-iron blocks, through which water circulates to keep them from fusing with the high temperature, while the bottom is of refractory sandstone. In front is a cast-iron dam-plate, furnished with a tapping hole for withdrawing the refined metal; the inner side being protected with brick or clay lining. A shallow mould, formed of thick cast-iron blocks, partially suspended in a cistern of running water, is placed in front of a dam-plate, to receive the charge from the



Sectiona Elevation of a Blast Refinery.

hearth; water also circulates in the tuyeres, to prevent their lower extremities from burning. The blast is admitted by a large pipe to the valve-box, from which its escape to the blast-nozzle is regulated by a closely-fitting stop-valve.

A single refinery, or one blowing from one side only, will have a hearth about three feet square in the inside, by eighteen inches deep; a double refinery, or one blown from two sides, has a hearth about four feet square and twenty-one inches deep, with pipes about an inch and a half bore at the point. A sectional elevation of a blast refinery is given in the preceding page.

The refining of the crude iron is conducted somewhat in the following manner:—The hearth is filled with coke, and the blast partially applied, until the interior has attained a high temperature. If working on cold iron, a quantity of pigs, weighing from twenty to thirty per cent., are thrown in on the incandescent fuel, and covered with additional coke. The full blast is now applied, and the fire urged so as to attain an intense heat; additional fuel being added as required until the pigs of iron soften, and gradually fusing, fall through the interstices formed by the coke to the bottom. By means of iron bars, the attendant keeps the infused portions of metal under the influence of the heat around the tuyeres; and, finally, stirs up the contents of the hearth, to ensure the perfect reduction of the entire charge. When the entire charge has been collected on the bottom of the hearth, the refining process may be said to commence. The union of the oxygen of the blast with the solid carbon combined with the metal, results in such a rapid evolution of gaseous carbon, that the mass spontaneously boils up, rising several inches: the superincumbent stratum of fuel rises also, and vibrates with the movement of the boiling metal, while innumerable minute globules of oxidized iron are thrown out of the chimney. Considerable skill is required in managing the blast to a successful issue. The angle at which the pipe dips into the hearth, appears to be of importance to the process; each refiner, however, works his blast according to his own judgment. The several portions of the charge are successively brought under the oxidizing influence of the blast, so as to be equally acted upon, until the major portion of the carbon being disengaged, indicates the approaching completion of the process. The fireclay "stopping" of the dam-plate is now removed, and the metal and cinder allowed to flow into the shallow mould in front. When collected in the mould, the water is thrown rapidly over it, cooling the surface portions, and, at the same time, oxidizing a portion of the iron. The cinder, by its inferior specific gravity, separates itself from the metal, rising to the top, in which it is partially assisted by the attendant beating the molten mass with an iron bar. On the first application of water, the steam produced lodging in the viscid cinder, swells it up several inches; this is broken down by the beating as fast as it rises, in order that the water may the more readily reach the lower portions.

When cold, the plate of refined iron, which may be about three inches thick by three feet wide, is removed by a carriage to the bank, where it is broken into pieces of a size convenient for the succeeding operation of puddling. The fracture of good metal exhibits a silvery whiteness, while that of inferior kinds is perceptibly duller. On the surface it is rough, and covered with irregular cavities, to which the name of *honeycomb* has been given from some fancied resemblance to that substance. The depth of this cellular struc-

ture varies with the quality of the metal and length of blowing, being least in the best irons with a limited blowing.

The chemical effects of the blowing are not well understood, researches into the several reactions which take place in the hearth having been almost wholly neglected. By carefully analyzing the resulting fine metal and its accompanying cinder, and comparing the results with the analyses of crude iron and cinder, some light was thrown on the subject, which, pending the completion of extensive experimental researches now in progress, the author would sum up as follows:—The metal and cinder together represent the crude iron, with oxygen derived from the blast, and solid matters derived from the fuel: the quantity of matter derived from the material of the hearth is too inconsiderable for remark here. Refinery cinder contains a large per-centage of silica, which must have been derived principally from the iron; it also contains protoxide of iron to a large amount, from the same source; phosphoric acid is a constituent to the extent of three to four per cent. in some specimens; sulphur is a common ingredient, but may have been derived in part from the fuel. Manganese, magnesia, and lime exist in small quantities; alumina to the extent of five or six per cent. After deducting the ash of the fuel and the protoxide of iron, there remains a considerable quantity of earthy matters, the presence of which can only be accounted for on the supposition that they have been derived from the crude iron, and that to this extent the cast-iron has been purified of alloys.

Puddling the Refined Metal.—The further refinement of the iron from the blast refining-furnace is conducted in reverberatory furnaces, technically termed "puddling-furnaces," in which, by skilful manipulation, it is deprived of most of the remaining alloy. The puddling-furnace consists of a rectangular erection of iron plates, nearly six feet high, the same distance between the two sides, and twelve feet long, lined throughout with fire-brick. At one end is a fire-place about three feet square; divided from the fire by a brick bridge is the body of the furnace, six or seven feet long, and three and a-half feet wide at its widest part, resting on a cast-iron bottom-plate, on a level nearly with the bars of the fire-place; the farthest end of the furnace is contracted to eighteen inches in width, where it joins a brick chimney thirty-five to forty feet high, furnished with a damper at top. The furnace is arched over with fire-brick; and to prevent the sides from being thrust out by the expansion of the heated bricks, a number of stout wrought-iron bolts connect the two side-plates, which receive the thrust of the arch. At one side of the body a working-door is placed, in a stout cast-iron frame; the bottom eight or ten inches above the iron bottom of the furnace. The door is moved vertically by a balanced lever, the inner side fitted with a brick-protecting lining, and is furnished at bottom with a small notch, for the insertion of the iron bars used during the operation. The fire-place has a small lateral opening for charging fuel, which is afterwards stopped by a large piece of coal. The cinder produced during the puddling process flows over a small bridge in the flue, and through an opening in the bottom of the stack to the outside. To maintain the stream of cinder sufficiently liquid for running, a small coal-fire

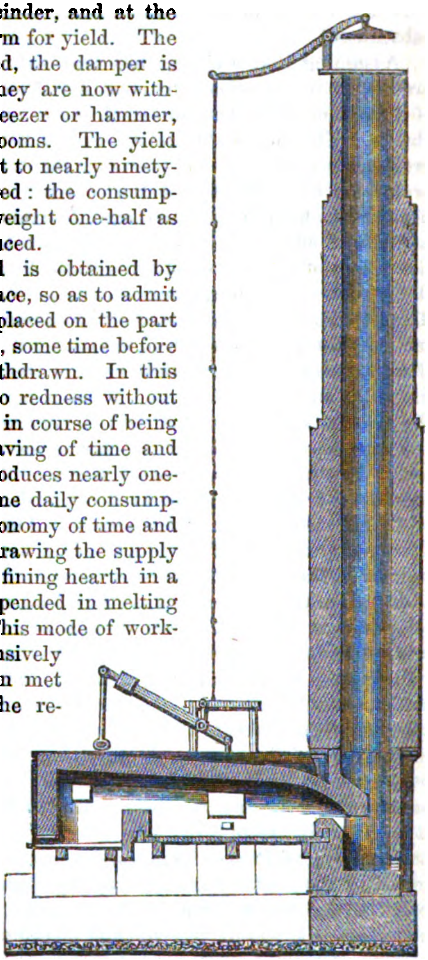
is maintained at the foot of the chimney, from whence the cinder flows into a receptacle provided for the purpose.

The cast-iron bottom plate is supported at short intervals by cross-bearing bars and pedestals; air is allowed free access to it from below. Indeed, without this precaution, the bottom would be immediately fused. Occasionally a portion of the brickwork of the side of the furnace next the body or working part is removed, and cast-iron blocks, cooled by a current of air or water, substituted.

Assuming that a charge has been withdrawn from the hot furnace, the process is recommenced by charging through the furnace door a quantity of refined metal, broken into small pieces: from four to five cwts. constitute a charge. The pieces of metal are evenly distributed over the bottom, as far as practicable in an inclined position; the door shut, and a little dust thrown around its edges to exclude the cold air. Attention is now directed to the fire, which should be cleaned, fresh fuel added, and the damper fully opened, to allow of an intense heat being generated in a few minutes. The edges of the pieces of metal soon attain a white heat, and begin gradually to soften; the portion of the charge next the fire-place attaining a melting temperature. The "puddler," as the attendant workman is called, with a stout iron bar inserted through the notch in the door, lifts up the coldest pieces and pushes them forward into the hottest parts of the furnace, until the whole is nearly dissolved into a liquid mass. When a portion of the iron has been melted, the hooked bar is inserted, and the entire mass raked up and exposed to the reverberating action of the hot gases from the fire. At this stage the inside of the furnace presents a scene of intense brightness, and an inexperienced eye is unable to distinguish the metal through the dazzling whiteness of the whole of the interior. Through the small notch in the door, the puddler conducts the operation by constantly raking up the fluid iron, in order that the gases of the reverberatory current may play on the whole, thus lifting from the bottom any portions that may have set, through lowness of temperature. Since the current has no power to penetrate the liquid iron, and thus combine with the carbon and other alloyed matters, as in the blast-refinery, the puddler's principal duty is to mechanically agitate the particles, so that every portion may be successively brought in contact with the free oxygen in the current. The assistant puddler attends to the fire, which he maintains in full activity; at other times he relieves his partner, or works in conjunction with him. After some time thus occupied, the puddler will have separated the larger portion of the alloyed matters from the iron, and brought it to that point technically known as "coming to nature." When this is the case, the metal is seen to attain consistence, and a curdy-like matter is collected by the hooked bar; this rapidly augments, until a sufficiency has been collected together to form a ball or bloom. A second, third, fourth, and fifth collection is successively made and placed aside in the furnace. The charge of refined metal will thus have been converted into five portions, but some workmen divide it into seven or eight. While collecting the metal into balls, a somewhat lower temperature prevails; but immediately they are formed, the

damper is again opened, and the heat of the furnace forced, so as to rapidly agglutinate the particles of metal in the balls. During the raking and stirring of the fluid iron, the door is wedged fast in the frame, for which purpose the latter requires to be made very strong. This securing of the door is especially requisite in forming the blooms, since with the heavy hooked bar it affords the puddler an excellent fulcrum for compressing and hugging the ball, to expel as much as possible of the cinder, and at the same time give it a favourable form for yield. The formation of the balls completed, the damper is lowered and the door opened: they are now withdrawn and conveyed to the squeezer or hammer, for compression into oblong blooms. The yield or produce of blooms will amount to nearly ninety-five per cent. of the metal charged: the consumption of coal-fuel averaging in weight one-half as much as that of the blooms produced.

A superior economy of fuel is obtained by lengthening the body of the furnace, so as to admit of the succeeding charge being placed on the part of the bottom adjoining the stack, some time before the charge under operation is withdrawn. In this way the new charge is heated to redness without serious detriment to the charge in course of being balled up, and a considerable saving of time and fuel is effected. The furnace produces nearly one-fourth more blooms, with the same daily consumption of fuel, by this process. Economy of time and fuel is still further increased by drawing the supply of refined metal direct from the fining hearth in a fluid state; the fuel and time expended in melting the iron being thereby saved. This mode of working, however, has not been extensively adopted; difficulties having been met with in effectually separating the refined iron from its accompanying cinder.



Section of a Reverberatory Refining Furnace.

The refining of crude iron in the reverberatory furnace, embraces in one furnace the separate operations of refining and puddling. In dimensions and general arrangements, the furnaces employed, known in the trade as "boiling furnaces," are very similar to puddling-furnaces. The charging and first part of melting are similarly conducted in

both processes; but after the fusion of the crude iron on the bottom of the furnace, the appearances presented are very dissimilar to those with refined metal. At first the liquid iron forms a level sheet, which gradually swells up with the rapid manipulation of the workman, until it has risen six or seven inches above its former level. The entire mass appears to heave and boil; innumerable eruptions arise on its surface; and bursting, discharge their pent-up gases. The puddler must be incessant in his manipulations; every portion is to be raked up and exposed to the oxidizing influence of the current of the gases, until the diminished action shows the near completion of the refining part of the process. At this stage a careful manipulation, with a judicious regulation of the temperature, results in the segregation of the iron into particles of a pasty consistence, which eventually agglutinate by pressure into masses of the required size for blooms. The conclusion of the process, the drawing-out of the blooms and recharging, differs from this part of the puddling process only in the tapping off the larger portion of the cinder produced previous to recharging.

The rising of the molten mass appears to result from the expansive action of the recently-formed gases against the viscid cinder. By attention to the temperature and consistence of this cinder, the rising may be partly controlled; but the nature and quantity of the alloyed matters greatly influence the process. Since the carbon combined with the metal has to be eliminated, by first converting it into carbonic acid, a greater or less amount of carbon will result in a corresponding rising, and lengthened manipulation, for its exposure to the oxygen of the reverberating column from the fire-place. Iron containing a maximum per-centage of carbon, with a deficiency of earthy matters in alloy, is refined with difficulty; and requires an addition of cinder from the mill-rollers, to protect the metal from a too rapid oxidation. Crude iron of this character also works hot in the furnace, and great difficulty is met with in bringing it to the agglutinative point for balling up. This probably arises from the heat evolved by the combustion of the excessive per-centage of carbon in the crude iron. Where the quantity of carbon is large, as in the Scotch irons smelted from carbonaceous ores, the heat thus evolved, with an ample supply of air, is sufficient to raise the temperature to a degree injurious to the successful manipulation of the iron, and dangerous to the metal bottom. Throughout the process, also, the temperature, from the same cause, is less under the control of the workman.

Various inventions have been tried as auxiliaries for the more perfect separation of the matters in alloy, but very few have stood the test of experience. The application of steam, at one time, promised to be an essential improvement. High-pressure steam was conveyed in pipes to the bottom of the molten iron in the blast or reverberatory refining-furnace; and in its escape upwards, agitated the iron, thereby increasing the surface exposed to the action of the air in the gaseous current from the fire-place. The white-hot iron decomposed the steam into its elements of oxygen and hydrogen; a portion of the former reacted on the carbon in the mass, producing carbonic acid, while the latter was free to combine with any sulphur present. With

some irons, the increase of temperature on the combustion of the carbon was considerable, and greatly expedited the operation. Theoretically, it seemed that the use of perfectly dry steam should leave little to be effected in the way of refining crude iron; and the fact of the invention having been re-patented five or six times within the last few years, shows that much attention is directed to it. Nevertheless, the use of steam has been abandoned in the works where first tried, and the realization of the theoretical advantages is still a desideratum, Mr. Nasmyth, who last tried the experiment, having come to the conclusion, after many experiments, that the steam-condenser had the effect of reducing the temperature of the metal in the furnace.

The separation of the alloyed matters has also been attempted, by adding in the refining process various substances, singly or in mixture. One of these mixtures consists principally of oxide of manganese with charcoal, plumbago, and nitrate of potash. In a second mixture, the ingredients were tap cinder, hæmatite ore, coke dust, fire-clay, and chalk; a third was composed of sulphur, nitrate of potash, potash, borate of soda, and sulphate of alumina; a fourth consists of peroxide of manganese, common salt, and potter's clay. These and other patented compositions, however, have not answered in practice. Ground hæmatite, nearly free from silicious matter, added in small quantities at a time, facilitates the puddling operation, as also do rich oxides generally; but it is essential that they be free from deleterious substances.

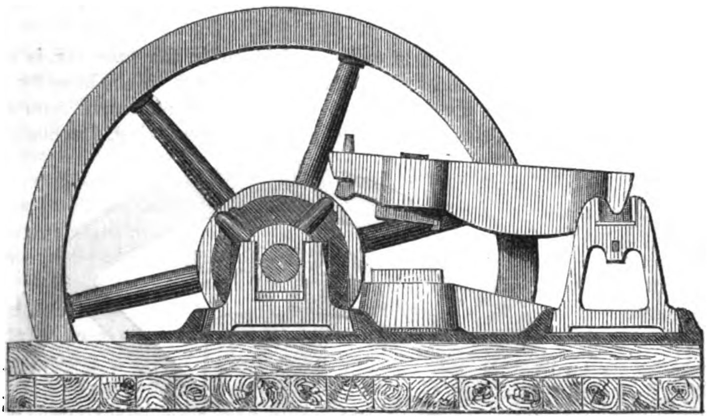
The refining of the iron by the decomposition of water, has also been several times attempted. This is done by pouring the liquid iron into a quantity of water sufficiently large to prevent the iron heating it above the boiling point. The white-hot iron, falling in finely divided streams, decomposes a portion of the water, liberating oxygen, which reacts on the carbon; the hydrogen, similarly set free, acts on the sulphur, thus forming sulphuretted hydrogen. Cold iron, immersed in water, appears to slowly undergo a similar alteration of composition; but in this case a portion of the metal is oxidized. The invention is a very old one, having been used more than half a century ago. It was recently made the subject of a patent, which a professor of metallurgy, in his inaugural address, adduced as a striking instance of the ignorance prevailing among manufacturers. Chemically, however, the discharging the iron into water, is a valuable invention; while, practically, the odour of sulphuretted hydrogen, evolved during the pouring of sulphury irons, is too apparent to doubt the good effect produced on the quality, when the operation is properly conducted.

The refining of iron in reverberatory furnaces, is sometimes practised on the liquid metal run direct from the blast-furnace. A saving of fuel results from this procedure, and the quality appears to be slightly improved when skilfully conducted. It necessitates the erection of the reverberatory furnace and forge close to the blast-furnace, which is a disadvantage in the majority of works, and leads to a temperature in the forge almost unendurable.

Shingling Puddle Balls.

The white-hot balls of the puddling furnace are removed to the hammer,

to be further shaped before passing through the rollers. The forge-hammer, or helve, is usually of a T form on the plan, resting at each wing on cast-iron pillars, fixed in ponderous standards, and lifted at the narrow end by projecting cams fixed in a cast-iron ring piece, which receives a revolving motion from a steam-engine, or other motive power. The anvil is fixed in a



Elevation of Forge-hammer.

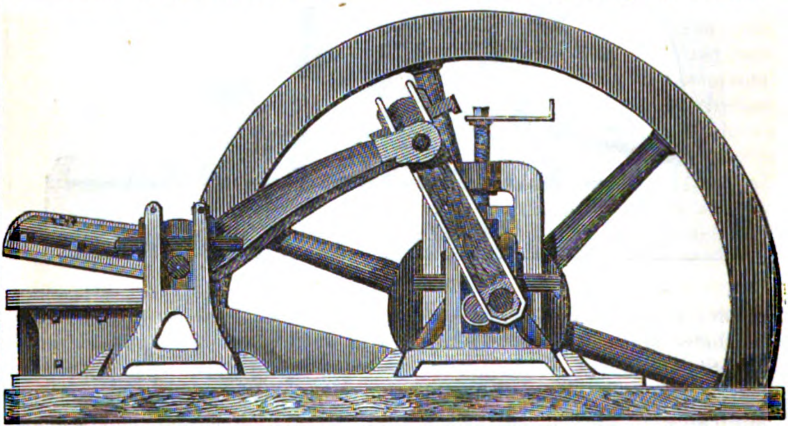
massive iron block, weighing several tons, situate between the cam-ring and helve standards. The hammer is a loose piece of iron fixed in a socket in the helve. When not in operation, it is propped up at a distance above the anvil, and beyond the reach of the cams in their revolution. The entire apparatus rests on a stout iron bed-plate, which is firmly spiked down to a ponderous wooden bedding, employed for the purpose of reducing, as much as practicable, the injury which results from the vibration of the blows.

The hammer-man takes hold of the hot puddle-ball, and lifting it on the anvil, allows the hammer to fall on it a few times, giving it a turn between each blow to approximate it to the square or cylindrical form, as may be desired. He then skilfully raises it on end; and allowing the hammer to give it a couple of blows in this direction, completes the "upsetting," as it is technically termed, and again proceeds to the reduction of the bloom to a short bar five or six inches in diameter. The effect of the severe hammering is to expel a large quantity of the cinder wrapped up with the iron in the porous puddle-ball, and by condensing the particles, otherwise improve the quality of the product. Hammering each ball lasts twenty-five or thirty seconds, in which time it may receive thirty or forty blows. To keep the anvil cool, and prevent the adhesion of cinder, a small stream of water is occasionally directed on it. The still red-hot bloom is taken direct to the roughing rollers of the puddling train, and rapidly rolled down to a bar.

The forge-hammer has been nearly supplanted by the squeezer, a modern

contrivance of some merit. It consists essentially of a ponderous cast-iron lever, vibrating on centre gudgeons, and wrought by a connecting-rod attached to the crank, placed on a level with the puddling-rollers. The under surface of one end carries a hammer face; underneath this is fixed to the massive framework of the apparatus a long and somewhat broad anvil block: both hammer and anvil are kept from burning out by a stream of water circulating through them.

The reduction of the ball to a cylindrical bloom in the squeezer, is performed by a series of squeezings; but as the stroke given to the lever by the crank is invariable, the space between the hammer and anvil regularly diminishes towards the fulcrum. In the process of squeezing, the bloom is

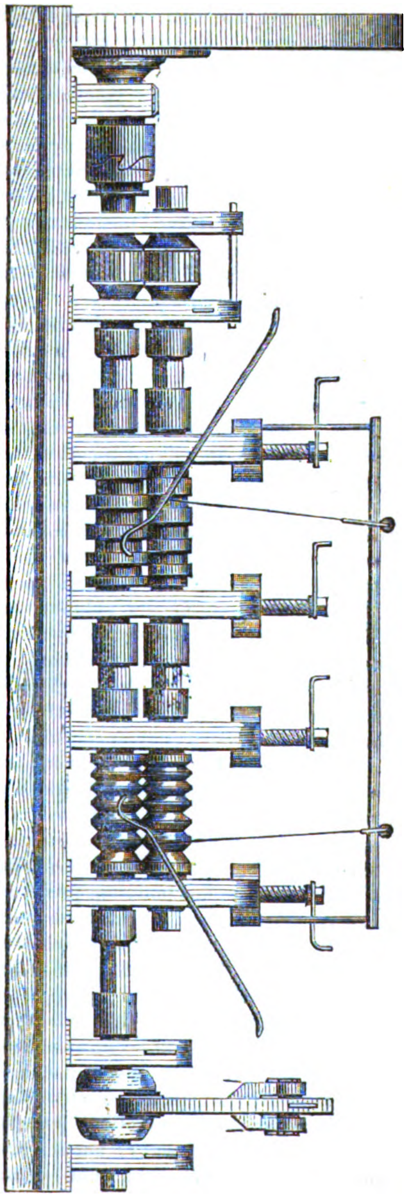


Elevation of Lever Squeezer, and end view of Puddle Rollers.

rolled over, at each stroke of the lever, by a movement of the tongs, to the narrow part, until the required diminution of size has been effected. The upsetting is performed at the extremity of the lever, where the stroke and space together afford ample height for the bloom endwise. Care is required on the part of the shingler, that the ball, if hard, is not rolled towards the fulcrum too rapidly; for if this should occur, the apparatus must give way in some part.

Lever squeezers, in their turn, have had to compete with numerous inventions professing to perform the blooming of the ball better and at a cheaper rate. Few of them, however, have been able to stand a preliminary trial; and even those invented by practical iron-masters have had to succumb to the common squeezer and hammer. The cost of blooming by either of these apparatus, in a well-arranged forge, working to its full power, amounts to only fivepence per ton, including interest on capital and repairs. In devising a substitute for either, it is necessary to bear this item in mind; for it is very evident that an apparatus which works at a higher rate cannot successfully, in a commercial point, compete with its cheaper rival.

The steam-hammer has likewise been pressed into the service of the iron manufacturer. This apparatus answers admirably the varying work of the engine-maker and millwright; but for iron-making purposes it possesses no superiority over the common forge-hammer, though several times more costly. The balls of porous iron from the puddler are so nearly alike in size and hardness, that little variation is required in the blows, which the common hammer gives with great rapidity.



Elevation of Puddle Rollers, and end view of Lever Squeezer.

Rolling the Bloom.

The bloom from the hammer or squeezer is passed first between a pair of roughing-rollers (in Staffordshire they are called "bolting-rollers"), and then between a pair of finishing-rollers, to convert it into a flat bar. The two pairs of rollers, and their connecting spindles, pinions, frames, and appendages, are technically called a "train." Commonly, the rollers are sixteen or eighteen inches diameter, and three or four feet long, with end bearings nine or ten inches diameter, and square or fluted projecting ends, by which they are driven. They are cast of tolerably hard iron, and turned in a lathe to the required longitudinal section. Very strong pinions couple together the top and bottom rollers, so as to deliver the iron simultaneously in the same direction. The cast-iron frames require to be exceedingly massive, and substantially fitted with adjusting screws

and nuts. At one end, the train of rollers is connected to a prime-mover (generally steam), by which they are driven at the rate of sixty or eighty revolutions per minute. The inequalities of motion, which otherwise would be very great, are met by a ponderous fly-wheel, revolving with the same, or even greater, rapidity, than the rollers. The general arrangement of a puddle-bar train, including the squeezer, is represented in the preceding engraving; the end view of the same in page 228.

The bloom is first passed through the largest groove; it is then lifted back over the top roller, turned one quarter around, and passed through the next smaller; repeating the process until it is reduced to a square bar, sufficiently small for entering the flat grooves of the finishing-rollers. In the finishing pair of rollers, a repetition of the rolling and returning reduces it to the required thickness, when it is delivered as a puddle-bar. From first to last, the bloom passes through nine or ten grooves, and is reduced from five inches diameter and fifteen inches long, to a flat bar three inches wide, three-quarters of an inch thick, and eleven feet long. The rolling and returning over the rolls occupies a minute and a quarter; the shingling, half-a-minute; and from the charging of the refined metal to the delivery of the finished puddle-bar, nearly one hour and a half will have elapsed.

A considerable difference is observed in the quality of puddle iron, from the two methods of refining. The blast-refined iron possesses greater fibre, and altogether produces a better malleable iron, than the product of the reverberatory furnace. Chemical analysis shows the latter to contain an excess of phosphorus and sulphur, and also a larger quantity of silicon. Their presence in greater quantity seems to point to the incompleteness of the reverberatory process for refining. The irons made by this process are very generally hot-short (that is, brittle when hot), and incapable of being rolled into some intricate forms of finished bar-iron. When cold, however, the purest specimens possess considerable tenacity.

It is a question whether the cleansing the iron of the alloyed matters can be efficiently performed in a single operation, without the employment of a blast. Chemically, the constituents of refined iron from the blast-refinery accord very nearly with the composition of puddle-bar from the reverberatory refinery. Hence the bars from the former are more pure, by the quantity of alloy removed in the puddling process. This defect of boiled bars deserves the serious consideration of manufacturers in more than one district, which recently has lost its character for making superior qualities of merchant iron.

The matters in alloy are principally derived from the ore; the sulphur partly from the fuel. In the preparation, then, of the best irons, especial attention must be paid to the constituents of the ore used in the smelting-furnace. If these are unfavourable as to quality, it is hopeless to attempt the complete separation of the injurious ingredients in subsequent processes, other than with a ruinous waste of metal and labour. The blast refinery removes a portion, the puddling process a second portion, and the reheating furnace a further quantity; but the resulting malleable iron is still contaminated by the presence of minute quantities of the alloy, which it is nearly

impossible to wholly eradicate. Phosphorus and sulphur are commonly considered the substances which exercise the greatest deteriorating influence on quality; it is, however, highly probable that silicon, calcium, magnesium, and a few other substances, impair the quality to nearly an equal extent.

The cinders produced in the puddling process appear to be of a different composition to those from the boiling furnace. The latter display a larger amount of lime, phosphoric acid, sulphur, and silica; in fact, are not widely different from some varieties of the blast refinery cinder. By adding together the constituents of the refinery and puddling cinders, it is seen that the proportion of injurious matter removed, relatively to the quantity of iron, is very much larger than in the boiling process.

A difference of quality is observed between the iron worked with a forge-hammer, and such as is worked with a squeezer. The former is found to be more tenacious, and freer from cinder, than the latter. This difference, it is generally believed, arises from the motion of the squeezer, which is gradual and pressing, while the hammer violently expels the impurities by heavy blows given in quick succession. A preference is very generally given to the hammer, where the quality is considered of paramount importance.

The balling-up of the iron in the puddling process is a highly interesting point in the manufacture, insomuch that it forms the connecting link between cast and malleable iron. Up to this point in the operation the iron is brittle, devoid of malleability, and melts readily at a temperature between 2000 and 3000 of Fahrenheit's thermometer. After the balling-up and the manipulation of the shingle, the iron is malleable, tenacious, and fuses only at a very high temperature.

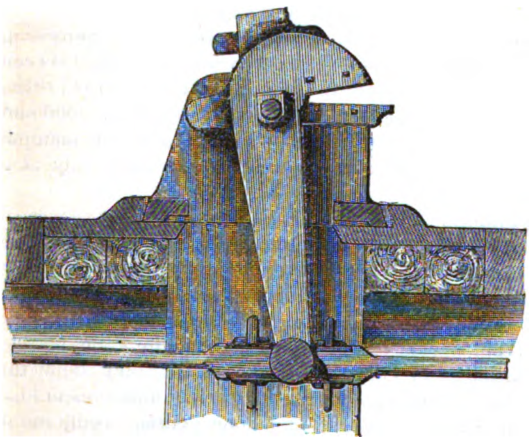
Chemical analysis hitherto has failed to inform us of the cause of malleability in iron, since no appreciable difference can be detected between bar-irons and some crude cast-irons. The latter may be deprived of its alloy so as to produce an iron similar in composition to bars, yet the malleable principle is wanting. Crude cast-irons made from the rich hæmatites of Lancashire and Cumberland, appear to be less brittle than others, and possess a limited amount of elasticity; in other respects, however, they show the characteristics of cast-iron. Exposing thin castings from these ores to heat along with ground hæmatite in close vessels for a long period, results in the abstraction of most of the carbon, and the consequent production of limited malleability. Attempts have been made, and are now making, to convert the crude cast-iron into wrought-iron, by a system of blast-refining without fuel, and subsequent application of the hammer or squeezer,—a process which we shall describe in detail, although it has not as yet attained such certainty as to justify a decided opinion of its merits. Mere refining, however, even with the addition of fluxes, fails to produce malleable iron. Manipulation to a certain extent is essential to the development of the malleable principle, which then progresses proportionately with the working. Various oxides and sulphurets, however, possess the property of retarding and sometimes entirely destroying the agglutinous character of the iron at the critical point. Their

presence is shown by the inability of the puddler to ball up his iron, which persists in retaining the consistence of a dry pebbly mass.

The welding principle of wrought-iron, also developed at this critical point in the operation, is equally characteristic of the singular properties of the metal. Here, also, analysis fails to point out the acting cause why some irons are capable of welding, and others not; nor does it explain the reason of iron being so pre-eminently distinguished for this property over all other metals. Various theories have been propounded; but the most feasible explanation of the welding appears to be the accession of a quantity of heat, sufficient for softening and uniting the two pieces by pressure, considerably before the temperature of fusion is attained. Metals apparently devoid of this principle, retain their hardness up to the moment of liquefaction; consequently no opportunity is offered for union in the malleable state.

Cutting Puddle Bars to Length.

This is performed by powerful lever shears, containing steel knife edges, driven by the same power as the rollers, and at nearly similar velocities. The proportions of the shears intended for cutting bars cold, are considerably heavier than for bars direct from the finishing rollers. Knives, four inches deep, one and a half inch wide, and sixteen inches long, bolted to the fixed and moveable arm of the apparatus, are a common proportion. Great care is required that the knives pass each other with a certain degree of tightness, or the wedge-like action of the flat bar at the point may break off the moveable arm. This is more especially the case with shears for cutting cold iron, which, in addition to being kept in contact, require the knives at all times to be clean with a sharp V-cutting angle. The knives of shears cutting hot bars are kept from softening by a small current of water directed against them; but the same degree of sharpness is not required here as in cold shearing.



Shears for Cutting to Length.

Piling the Cut Puddle Bars.

To convert the puddle bars into the various forms of the finished malleable

iron met with in commerce, the short pieces from the cutting-shears are piled one on the other to form a mass of a weight suited to the weight of the bar to be operated on. The piles vary greatly in size and arrangement, according to the magnitude and purpose of the finished bar. If common bar-iron of average size be the order of the day, they will measure some two feet long and four inches square; with larger sizes they measure five or six feet long by ten or twelve inches square. A nearly uniform size in the pieces composing the pile, whatever be its dimensions, is essential to successful results. The piles are constructed to the number of six or seven, or more, on an iron frame standing about two feet above the floor, from whence they are taken as required by the workmen engaged in bringing them to a welding-heat preparatory to rolling.

Heating Furnace.

A reverberatory-furnace of nearly the same dimensions as the puddling-furnace, but having a refractory silicious sand-bottom, is employed in heating the piles. The bottom is rendered even, and declines from the charging-door to the back and flue, for the flow of the liquid cinder. Cast-iron framing, with tension bolts to restrain the pressure of the arched roof, and the same powerful chimney, are required as in the puddling-furnace. The piles are inserted into the furnace on a "peeler," and disposed on the bottom in such manner that the workman can readily turn them over, or grasp them for withdrawal. The number charged at one time is inversely as the size; but for small piles of the dimensions given above, they may be taken at eight or ten. When properly disposed on the bottom, the charging-door is shut and all entrance of air around it prevented by a thick dusting of small coal or ashes. The grate is now cleaned of adhering matter, coals added to the fire, the stoke-hole closed with the fuel so as to prevent the admission of air, and the damper opened to its widest. An intense heat is generated, and communicated by deflecting from the roof to the charge in the body of the furnace. The piles receive the heat unequally, those nearest the fire-place being heated first; it is the duty of the attendant to inspect from time to time the condition of the charge, and by exposing them alternately to the strongest action of the fire, to heat them to the same temperature, occasionally turning them over to expose the under side equally with the others. When the piles are large, turning over to heat the under side is the only operation to which they are subjected in the furnace. At a white heat the softening of the iron is followed by the flowing of a quantity of cinder from the interstices, which runs down the flue to the exterior of the chimney. Considerable dexterity is required in managing the fire; for though in theory the mere heating of a few masses of iron may seem a very simple operation, in practice it is difficult of attainment economically. The flow of cinder over the masses, when at a white heat, protects them to a considerable extent from oxidation; but great care must be taken that no air gains access to the iron during the process. If this precaution be neglected, and air enters the furnace, either through the fire being too open or the door imperfectly sealed, the metal is rapidly oxidized, and great loss

results. The particles of oxide of iron formed, eventually cool into brittle scales, which cut into the malleable iron, and destroy its continuity in the subsequent processes. If allowed to proceed, the oxidized surfaces of metal cannot be brought to a welding condition; and whatever pressure be applied, the pieces of puddle bar composing the pile cannot be forced into union.

It may here be remarked, that by bringing gaseous and solid carbon in contact with the oxide in the blast-furnace, the oxygen forms new combinations, liberating the iron in the metallic state. The superior affinity at high temperatures of carbon over iron for oxygen, has been taken advantage of from time immemorial for the ready separation of oxygen in oxides of iron. But in its progress from the blast-furnace to the state of a finished bar of malleable iron, in the absence of carbon, the iron has a constant tendency to return to the condition of an oxide. In the blast-refinery, one-half of the metal would be oxidized, were it not for the stratum of carbon fuel covering the molten iron, and which decomposes the oxide nearly as fast as it is formed. In the puddling-furnace the metal is unprotected by carbon, and the greatest care and skill is demanded from the puddler that a large portion is not lost through wasteful oxidation. The heating process is similarly situated; access of air to the iron causing a portion to revert to its original state in the ore. So much of the iron as is thus oxidized in the several processes passes back to the blast-furnace, to be again reduced by presenting to the oxide the carbon necessary for liberating the metal.

The heating the charge to the requisite temperature is accomplished in forty-five or fifty minutes, when the bars are withdrawn singly by grasping them with a pair of heavy tongs, and conveying them on a light carriage to the rollers. A frequent practice is to drag the white-hot pile on the metal floor of the mill to the rollers; but such a proceeding scarcely ever fails to soil the iron, and injure the quality to a slight extent. Where the quality is sought to be superior, too much care cannot be taken to keep the iron from contact with deleterious substances.

The cinder flowing from the iron is contaminated by the addition of a portion of the fused sand of the furnace-bottom, as also by the small quantity of brickwork of the interior fused by the intensely high temperature. The composition of the cinder varies with the iron and treatment; generally it contains sixty or sixty-five per cent. of protoxide of iron, twenty-nine or thirty of silica, with smaller quantities of protoxide of manganese, alumina, phosphoric acid, lime, magnesia, and sulphur.

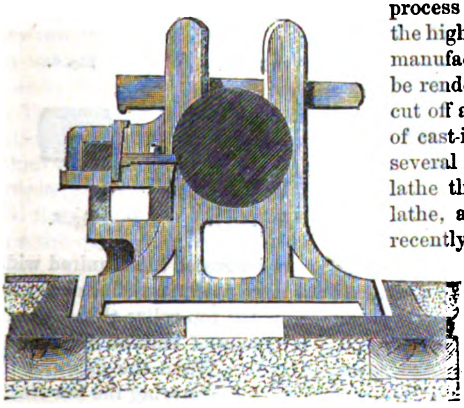
The Rolling Mill.

The rollers used in this process vary in size with the iron to be reduced: heavy bars are rolled between rollers of eighteen or twenty inches diameter; lighter bars between rollers twelve and fourteen inches; and the smallest sizes in mills have rollers six to eight inches diameter. A heavy rolling-mill consists of two pairs, distinguished as "roughing" and "finishing" rollers, with shears, saws, and other appendages for completing the operations on the bar, in addition to the eight or nine heating-furnaces. The roughing-rollers are

commonly about six feet long, the finishing about half as much; the two pairs are coupled as in the puddling train, and driven at speeds varying from sixty to a hundred and twenty revolutions per minute. The frames, sole-plates, connecting-spindles, and pinions, are required to be heavier than in the puddling process, and greater accuracy and finish are required throughout. When a steam-engine is employed to drive the trains, the size ought to afford 100 horse-power to each; but smaller rollers are driven with proportionately less power. The tooth-wheels to bring up the speed of the rollers, the fly-wheel to equalize the speed, and the shafts, framework of the mill, and sub-structure, require to be proportionately heavy and strong. All the parts subject to strain are made many times stronger than a casual spectator would consider necessary; this is done to avoid the loss of iron and labour, and the ruinous delay necessarily attendant on every breakage of the machinery employed.

Turning the Rollers.

The rollers employed are made of cast iron, of as hard texture as can well be worked; soft iron is inadmissible. They are allowed to cool in the mould, having been cast on end with a high pressure of metal to insure solidity in every part, without which they are useless; they are afterwards taken to the lathes, and placed in a centering-lathe for turning the axles. This is done by the projecting end of a wide chisel, firmly held horizontally by wedging in a cast-iron frame, and pressed against the metal of the roller by other wedges in the rear. Motion is communicated to the roller through the intervention of powerful spur-gearing, from a steam-engine or water-wheel. Though rude, this process is more expeditious than with the highly finished lathe of the engine manufacturer, which would speedily be rendered unserviceable if forced to cut off at each revolution a thick ring of cast-iron from a cylinder weighing several tons. From the centering-lathe the roller is taken to a second lathe, and placed in brasses on its recently turned axles; motion is here communicated to it through the intervention of strong tooth-wheels and spindles to the amount of two or three revolutions per minute, depending on the hardness of the iron and the size of the roller. With hard iron the velocity is reduced, to prevent softening of the steel cutting-tools by heating. The hardest rollers cannot be advantageously turned at greater velocities than one revolution in three minutes, but the majority of grooved rollers bear turning at the higher velocity.


Section of Lathe for Rollers.

The lathe in which the working part of the roller is turned, requires to be exceedingly strong; a minimum section of 100 square inches of iron in the weakest place is not too much.

The first operation performed on the body of the roller is to reduce it to a smooth cylinder of the same diameter throughout. This is done with chisels three or four inches wide, resting on iron blocks and secured in the desired position by wedging as in turning the axle. The best cast-steel, carefully tempered, is demanded for the cutting tools. When reduced to a perfect cylinder, the motion is discontinued, and the design inscribed on its periphery; the design varies with the section of the bar which it is intended to roll. If intended for a cylindrical bar, grooves nearly of a semi-circular shape are cut out by similarly shaped tools, during the revolution of the roller; square bars have the grooves of a triangular shape. On placing two of these together, it is obvious that they form either a square (Fig. 1) or circular orifice (Fig. 2), and if made to revolve so that the peripheries of the rollers when in contact move in the same direction and with the same velocity, a soft substance interposed is forced to the figure produced by their junction. On the other hand, the substitution of a plain cylindrical roller on one part, would result in the production of a bar having a section corresponding to the semi-circular or triangular form of the single groove used. The effect of this alteration on the sectional form of the rollers at their junction is seen in Figs. 3 and 4.

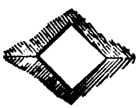


Fig. 1.

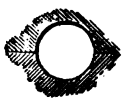


Fig. 2.

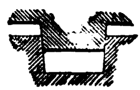


Fig. 5.


Fig. 6.


Fig. 3.


Fig. 4.


Fig. 7.


Fig. 8.

Flat bars are produced on similar principles: a groove of the required width is sunk in the roller much deeper than the intended thickness of the bar; the excess being filled up by a projecting tongue on the top roller (Fig. 5). By merely altering the distances of the two rollers, bars of various thicknesses may be rolled by the same pair of rollers (Fig. 6). When the depth of the groove is considerable, allowance has to be made for delivering the bar freely, by widening the top of the groove so as to give it a slightly tapering form (Fig. 7). This tapering, however, interferes with the parallelism of the sides of the bar, which has to be reversed and rolled in the finishing groove twice, by which the deviation from the parallel is reduced one half; except in very thick bars, the remainder is not readily perceptible to an inexperienced eye. A distorted figure of the section of a thick bar (Fig. 8), shows the effect on

the sides more clearly. By careful attention to the form of the groove and projecting tongue, very many apparently difficult sections may be rolled.

The reduction of the white-hot pile of puddle-bars to the finished merchant-bars, is accomplished by a succession of rollings, probably twelve or fifteen in number, each time through a groove smaller in section than the preceding one. This produces successive elongations, corresponding to the reduction of metal in section. It is, however, necessary to observe, that the groove through which the bar passes, while of a reduced section and smaller in one direction than the previous groove, in the other direction it is required to be larger. The rollers in their revolution are capable of pressing the iron in one direction only, viz. vertically: the degree of pressure exerted in this direction may be varied at pleasure, by allowing the rollers to recede from each other to diminish it, or the reverse by screwing them into closer contact with the ponderous set-screws in the frames. But the rollers are incapable of exerting any action horizontally on the iron in the direction of their length. If the bar is of a section that admits of turning on edge, and passing between the rollers in this way alternately, the width of each groove is gradually diminished, but it is in excess of the height of the preceding one. Squares and bolts are thus rolled; the horizontal axis of the bar being lengthened in the manner displayed in Figs. 9 and 10. Flat bars are rolled in grooves increasing in width to the last or finishing; but the thickness in each is diminished very rapidly. With very thick masses of iron of a flat-bottom section, it is not unusual to work half in each roll, and afterwards remove the angular piece at the side by repassing it through the last groove.

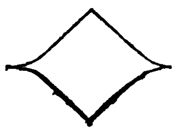


Fig. 9.

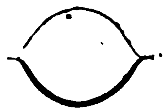


Fig. 10.

To ensure the delivery of the iron freely in a straight line without contortions, great attention has to be paid to the diameter of the rollers, at the points where they press on the iron. If one be larger than the other, the periphery of the larger roller, by moving at a greater velocity, deflects the iron from it. A groove or tongue of one roller of greater diameter on one side than the other, unless counteracted by a corresponding enlargement in the other roller, throws the iron out in a spiral direction, from which it is almost impossible to straighten it. This defect in the turning seldom occurs with bars of common section, but unusual sections entail a mass of unseen labour in guarding against its occurrence.

The interior of the grooves and the working part of the tongue, if any, it is preferable to keep smooth. This is absolutely essental in the case of the last grooves through which the bar passes. In the grooves of the roughing rollers, it is common to cut notches, or otherwise dent the working surface, to ensure a sufficient adhesion to force the bar through. This is met more effectively by increasing the diameter of the rollers to the largest practicable point. The use of notches, in any shape, injures the fibre of the iron, besides affecting the surface appearance of the bar.

Allowance has also to be made for the reduction of size which the bar undergoes in cooling from a red heat down to that of the atmosphere. The measure allowed for contraction is affected by the character of the iron, and temperature at time of delivery from the groove; but one-fifth of an inch may be considered a fair allowance for bars one foot wide.

Rolling Bar-iron.

The white-hot pile from the heating furnace is passed through a large groove in the roughing rollers, by pushing it forward on the fore-plate until caught and drawn through by the rollers. If the pile is well-proportioned to the groove, it passes through easily; but if too large, it may require blows from the iron carriage to make it enter the groove: should this occur, and the roughing rollers be a small distance apart at the largest diameter, the immense vertical pressure on the iron in the small groove, forces out a portion each side in the form of a thin flange. This has to be carefully guarded against, as from its thinness this strip of iron cools rapidly, and may become too cold for turning down and welding in the succeeding groove. The pile is now seized, by a second workman, with a heavy pair of tongs; and two hooked levers (see page 229), suspended by chains from the roof of the mill, are inserted underneath, lifting it up over the top roller and delivering it on the other side. In its descent the first workman turns it over at a right angle from its former direction, and pushes it towards the next smaller groove until it is drawn in. The lifting back and rolling operations in the roughing rollers are repeated till a suitable reduction has been made for the finishing rollers, to which it is eventually transferred, resting on the hooked levers. In these it is rolled five or six times, through as many diminishing grooves, to the required section, each time turned partly around, or the position in regard to the jointing of the rollers otherwise altered. With a heavy strain and soft iron, constant attention is paid to the action of the rollers, that no side flange be formed on the bar.

The top roller is made a fraction larger than the bottom, in order to throw the bar down on the guides as it is delivered by the rollers. The guides are two tiers of heavy wedges, the points of the top tier resting on the top of the bottom roller, while the lower tier is kept in reserve immediately below. In its delivery the bar is conducted in a straight line by these wedges, instead of turning down underneath the roller, as it otherwise would. If, from accident, the guides opposite any one groove are displaced, the end of the bar is likely to return under the roll, and be united with the other part into a solid ring. This outward accident may also occur through defect in the iron, the more so if partially oxidized by long exposure in the heating-furnace. In this case a portion of the pile separates from the rest, and following the course of the top roll, is welded into a massive iron ring. Considerable delay occurs under such circumstances, for operations must be suspended while the iron ring is being cut through; and this requires some time when the metal is five or six inches wide and half as much in thickness.

With some sections great exactness is required, and a deviation of the

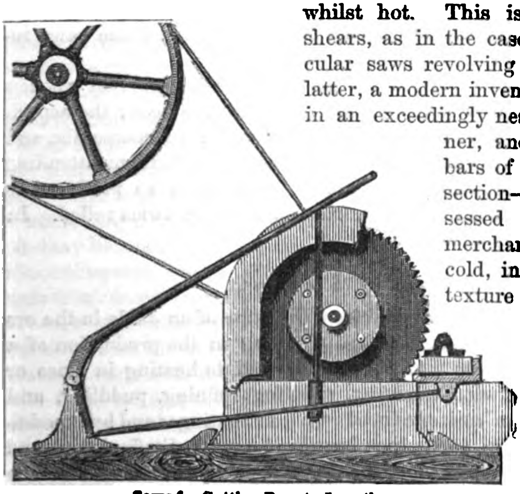
thickness of a hair either way renders the bar unsaleable. If obliged to work to a very exact section, the rollers are adjusted with the greatest care, the tightening and set-screws without play, and frequent examinations made of the bars produced. With the greatest care, however, a few days at most results in so much abrasion in the rollers, that they have to be sent to the turner for repairs. Where they rub on each other, the surfaces are frequently lubricated with black-lead and grease, or carbonaceous matter and palm oil.

The overheating of the rollers, by contact with the hot iron, is prevented by small streams of water directed on the parts of the finishing rollers liable to heating. With bars of a concave section on the upper surface in rolling, the water which falls on the red-hot charcoal affords an instructive example of the spheroidal condition of water in contact with substances at high temperatures. While the bar remains at a bright red-heat, no steam is formed, the drops of water merely rolling over the surface; but the surface of the rollers, though scarcely heated above the boiling point of water, is enveloped in clouds of steam. These phenomena of water were known to operatives in rail-rolling mills many years before the publication of M. Boutigny's experiments.

During the successive rollings, the great pressure exerted on the bar expels with violence a portion of the remaining cinder, and leaves the iron comparatively pure. This cinder is composed, to the extent of about ninety per cent., of magnetic oxide of iron: the remaining ten per cent. of silica, phosphoric acid, lime, sulphur, and other bases, depending on the local constitution of the crude iron.

Cutting Bar-iron to Length.

The finished bar is taken from the rollers and cut to the required length whilst hot. This is done either by lever shears, as in the case of puddle-bars, or circular saws revolving at great rapidity. The latter, a modern invention, performs the work in an exceedingly neat and expeditious manner, and is applicable to iron bars of all sizes irrespective of section—an advantage not possessed by any shears. Thin merchant-bars are frequently cut cold, in order to show off the texture of the iron; but large bars of every description are cut whilst hot. A side elevation of a sawing apparatus is here given. It consists of a pair of steel discs, four feet diameter and one-eighth of



Saws for Cutting Bars to Length.

an inch thick, with coarse teeth on the edges, mounted on a spindle about four feet long. By a small pulley-wheel on the centre of this spindle, motion is communicated by bands from larger wheels driven by the engine. Against the outside of each saw, but near its front edge, is placed a narrow sliding-frame of cast-iron, equal in length to the longest bar rolled, on which the red-hot bar is placed and retained in its position by stops. The ragged end of the bar is made to project sufficiently in front of, and finally pressed against, the saw, by which it is cut from the body in a few seconds. If gradually performed in fifteen or sixteen seconds, with good saws, the ends of the bar have a smooth, polished appearance; performed in three or four seconds, the ends are less smooth. The second end of the bar is cut in a similar manner by the other saw; the projecting ends cut off being placed aside for remanufacture. Great care is commonly required in cutting the second end, as the amount then cut off regulates the length of the bar. To ensure the requisite accuracy in this respect, the second moveable platform is furnished with a sliding-gauge, the distance of which from the face of the saw regulates the length of the finished bar. Allowance, however, has to be made for contraction of the bar from its red-hot state; and some attention requires to be given to the difference of temperature at which some are cut, in order to obtain bars of nearly uniform length.

The saws revolve 1000 to 1500 revolutions per minute, equal to a velocity at the cutting edge of 142 to 213 miles per hour. Their edges are kept from overheating by dipping into narrow cast-iron cisterns containing water. When cutting, the shower of sparks created is partially confined to the vicinity of the saws by sheet-iron casings, supported over the upper edges of the saw. The entire apparatus requires to be fitted up very correctly, the revolving parts evenly balanced, and working in good brasses rigidly fixed to pedestals and a heavy substructure. Every twenty-four hours the saws require sharpening, and are then replaced by others.

The cutting into lengths completed, the bar is straightened by wooden mallets on a massive cast-iron plane placed level with the floor; the asperities of the edge, from the action of the saw, removed with a coarse file, and the trade-mark of the maker stamped upon it; when the operations attending the manufacture of a merchant-bar terminate. The iron so produced is known amongst manufacturers as No. 2, from having been twice rolled. In commerce it is known as common bar-iron.

Recapitulation of the Process.

In tracing the progress of the metal from the state of an oxide in the ore through the several transformations, finally ending in the production of a bar of malleable iron, it is seen that recourse is had to heating in close or open furnaces five times; viz., calcining, smelting, refining, puddling, and heating. But frequently the bar is produced with four heatings; and by a modification of the refining process, at one time largely adopted in Staffordshire, and to a less extent in South Wales, only three heatings were required from the ore to the finished bar. In the first process—the calcining of the ore—it is

heated to a high temperature, and allowed to cool down for filling into the blast-furnace: the author is of opinion that this is a process properly belonging to the blast-furnace, where the calcination could be effected without loss of heat as at present. In the smelting process, the ore is again heated, fused along with fluxes, and descends to the lower hearth as crude iron, whence, in many works, it flows, without cooling, into the refinery furnace. The product of this furnace may either be malleable blooms, or refined metal, according to the kind of furnace used.

Assuming that the crude iron is refined by the boiling process, the heat imparted to the metal in the blast-furnace will last through the whole process of refining, balling-up, conveyance to hammer or squeezers, shingling, removal to the rollers, rolling in two pairs of rollers, removal to the shears, and cutting into short lengths. It is now allowed to cool; is piled, and the mass heated in the heating furnace, from whence it is taken to the roughing-rollers, where it is roughed to a thick massive bar; removed to the finishing-rollers, and rolled to a square, round, or flat bar, as may be required. It is now drawn out, the ends cut with the circular saw; straightened, filed clean at the ends, and, finally, stamped with a trade-mark and placed aside as a finished bar, with one single heating.

The several mechanical operations performed in the forge and mill on masses of iron weighing several cwts., are executed with admirable precision and dexterity. Frequently, the same bar is passed fifteen or sixteen times between the rollers, and has to be grasped and released twice this number of times with a pair of heavy tongs, when moving at the rate of nearly six miles per hour. In its progress, also, in the rollers it has to be adjusted in a different direction each time it is passed between them. When it is considered that the substance thus handled is a white-hot piece of iron, exposing a surface of from twelve to thirty-five feet to the operatives, and in a temperature compared with which the torrid zone is cold; the great skill of the men, and the severe bodily labour, will be seen to surpass everything having the least analogy in the industrial arts of any country.

From the period when the bloom leaves the puddling-furnace to the delivery of the puddle-bars from the shearing apparatus, five or six minutes will have elapsed: the time occupied in conveying the pile from the heating-furnace, and submitting it to the several finishing operations, seven to eight minutes.

It may be remarked, that in both pairs of rollers in puddling, and also in the rolling-mill, the violent compression of the iron is attended with the evolution of large quantities of caloric; so much so, indeed, that it compensates, to a great degree, for the loss by radiation and from the currents of water thrown on the finishing rollers. The quantity of caloric thus evolved, appears to vary with the character of the iron. The South Wales irons require to be rolled quickly, or the bar becomes too cold and hard for compression. South Staffordshire iron, on the other hand, may be rolled slowly, and is compressible between rollers at greatly lower temperatures.

The expenditure of power in forcing the iron into shape in the larger mills is very great. Fly-wheels, eighteen feet in diameter, having fifteen tons of

metal in the rim alone, and propelled by powerful engines at the rate of 120 revolutions per minute, are brought down to half this speed in four or five seconds, simply from the resistance of the iron to compression, when from any cause the temperature is slightly reduced. The expenditure of force in reducing a pile to a flat bar six inches by one inch, and fifteen feet long, is equal to the lifting of 4500 tons one foot high.

Manufacture of Railway Bars.

This branch of iron industry has sprung up within the last thirty years, in which short period the demand for rails alone has increased to an amount greatly in excess of the entire iron manufacture at the commencement of the railway system. The railways of this country, the Continent, Africa, Hindostan, the West Indies, and North and South America, have been constructed nearly altogether with iron from the rolling mills of South Wales, South Staffordshire, Scotland, and one or two minor seats of the manufacture. The several railways already constructed, British and foreign, have absorbed, of British manufactured iron, nearly 9,000,000 tons of heavy malleable iron rails, and 3,500,000 tons of cast-iron appendages (exclusive of the quantities used in the manufacture of the rolling stock and implements of construction); thus representing the disposal of a total of nearly 16,000,000 tons of crude iron.

The supplying of this large quantity of iron has necessitated important alterations in the rolling department of the large works. Mills for rolling railway-bars are constructed of the heaviest proportions, and fitted with a larger number of heating furnaces than other mills. At the same time a corresponding increase in the production of the mill has occurred; and an average of 120 tons at the commencement of the railway-bar trade is now augmented to 500 tons, and in some cases even 1000 tons in a week have been accomplished.

Rolling railway iron is conducted in a nearly similar manner to that pursued with other large bars. The piles are larger; and if a superior quality is desired, great care is taken in the arrangement of the several pieces of puddle-bar. In the finishing rollers, the reduction to the ultimate section is performed by a succession of intricately-shaped grooves. The turner's skill is

severely taxed to adapt the grooves in these rollers to each other, and at the same time to deliver a clean bar of the precise section. This frequently

requires a careful selection of the ores used in the production of the crude iron of part or the whole of the puddle iron in the pile, according to the strain exerted on different parts of it in rolling to a bar. A sketch of the grooves formed by the junction of a pair of rollers for rolling a common form of railway bar, the T or web-footed section, is given in the preceding figure, by which the configuration of the descending series is seen. The bar first enters the groove on the left-hand side, and is successively passed on to the right-hand groove, from whence it emerges exhibiting the required section. This form of bar is one of the most difficult to roll. It will be observed that a considerable portion of it is thin, consequently liable to cool quickly. A still greater difficulty is met with in the difference in diameter of the working portions of the grooves; the smallest diameter occurs at the edges of the thin flanges. In consequence of this difference of diameter, the several portions of the bar are not propelled with the same velocity; the greatest movement occurring with the largest diameter, and *vice versâ*. With wide flange rails the difference is very considerable; for instance, the part of the roller bearing on the body of the bar will move at the rate of six miles, while the bottom of the groove, which presses on the flanges, will move only five miles per hour. The distension of the parts of the bar is in direct ratio to the diameter of the roller of that part; hence, a direct tendency to drag the thick portion of the bar away from the flange. To counteract it, the thin part is spread out to great width in the second groove (see sketch); in the succeeding grooves the additional work thrown on this amply compensates for the lesser distension. Without a provision of this kind, the thin edges would crack; and not unfrequently long strips peel off, especially with iron of the red-short class.

Rail bars are cut into lengths with circular saws. In consequence of the hollowness at the sides or bottom they cannot be shorn hot with any degree of neatness; and the adaptation of cold shears to the purpose frequently leaves a hollow cavity in the end, and is altogether a tedious operation. The first bars manufactured were secured in heavy cast-iron blocks, fitted with counterparts, and closely fitting the rail all round. The end of the bar was made red-hot before insertion in the cavity of the block, and then cut with common blacksmiths' chisels, any inequalities being removed by filing. The substitution of revolving saws, however, has enabled the manufacturer to square and finish the ends at less than one-twelfth the expense incurred with hand-blocks.

After the ends are cleaned by filing with heavy double-handled rasps, the railway bar is subjected to the hot straightening process. This is performed on a massive iron block, placed over its surface the length of the rail, and cast of such thickness as will prevent flexure by heat. Any deviations from a right line are taken out of the hot bar by long-handled wooden mallets, having heads nine or ten inches diameter, and eighteen or twenty long: iron hammers would leave an impression on the soft iron, and are therefore inadmissible in all hot-straightening operations. If the section permit, it is now stocked on a level grated floor, formed of bars on edge, till quite cold.

With the majority of bars, however, it is subjected to a further hot-straightening, or, more correctly, hot-bending, to counteract the unequal contraction of the several parts of the bar during cooling. In the two sections (Figs. 1 and 2), the larger portion of the metal is thrown in the head or wearing part of the railway bar. If a bar of either of those sections be made perfectly straight when at a bright red heat, and allowed to cool, the thinner portions part with their heat and contract more rapidly, causing the rail to momentarily take the profile represented by Fig. 3. The head containing the great mass of metal cools very slowly; and several hours after the flanges have contracted nearly to the amount due to the reduction of temperature, this part continues to cool and contract, eventually causing the bar to take the form represented in Fig. 4.

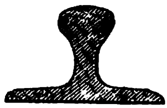


Fig. 1.

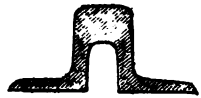


Fig. 2.

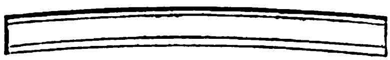


Fig. 3.

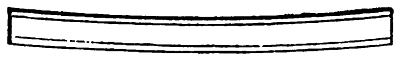


Fig. 4.

In practice this inequality of construction is obviated by curving the bar, in a reverse direction, to the amount of curvature which it would have taken if allowed to cool from a straight bar. The curve taken by a bar in cooling, forms the profile of a massive cast-iron block, over which the bars are successively bent with heavy wooden mallets. In doing this, attention is paid to the temperature so that no serious deviation occurs from that at which the trial rail-bar took its curve. Great care, indeed, ought to be taken to ensure the bar taking a straight line with its loss of heat, or permanent injury is caused to the iron.

If the hot-straightening and bending have been well conducted, the cold bar will not deviate greatly from a right line; but as absolute correctness is demanded by the purchaser, the bars subsequently undergo a series of cold straightenings by hammers or pressure. Formerly the heavy sledge-hammer (94 lbs. weight) was the only instrument used; but of late years the increased weight and stiffness of the bars, and the general desire to reduce the cost of manufacturing, have resulted in a very general adoption of machinery for this purpose.

The rail-straightening press consists of a massive cast-iron frame, with a projecting stand on each side to receive the railway bar; on the top revolves a large shaft, carrying an eccentric cam, which acts on a slider moving vertically in grooves in the large frame immediately over the projecting stand. The bottom of the slider is slightly bevelled, and at the down-stroke reaches to within four or five inches of the rail. When straightening, the bar rests on two shallow supports, about eighteen inches apart, on the stand, the convex side up; a wedge-shaped key is carefully inserted under the slider, so that at the lowest movement the slider presses on the rail through the intervention of the key, and removes, at one pressure, part or whole of the con-

vexity. The operation is repeated until all irregularities are taken out. If the bends in the bar are very short, a less distance between the supports is demanded. Considerable delicacy is required in using the taper key; if projected too far, the rail may be bent in the reverse direction, or completely broken if made of cold-short iron. Commonly the slider moves up and down about thirty times in a minute, thereby enabling skilful workmen to straighten 100 bars daily in a single press. The strain thrown on the approaches is very great, and renders it necessary to make the whole of massive proportions.

Frequently the bar, after leaving the straightener, possesses a degree of "winding" or twist, which is detected by placing the ends on two planed blocks accurately levelled on the upper surface. It is removed by grasping the ends with long levers, and applying a light torsional strain until the desired effect is produced.

Boiler Plate Iron.

This is made from selected No. 2 bar iron, when a superior quality is sought; but the larger portion of the present manufacture is rolled direct from puddle blooms. The pile for best plate is built short and wide, with an equal quantity of pieces running along and across it. They are brought to a welding heat in a reverberatory furnace of the ordinary description, and taken to the plate-iron rollers. These consist of two pairs, a slabbing and a finishing, both of a plain cylindrical form, chilled to extreme hardness on the surface. The frames in which the rollers revolve are furnished with large tightening screws (six or eight inches in diameter), by means of which the top rollers are screwed down or permitted to rise at pleasure. Commonly, a system of levers, carrying balance-weights, is appended to one or both top rollers, to diminish the weight on the other rollers. The coupling pinions connecting the top to the bottom rollers are frequently dispensed with in rolling thin plates.

The short flat pile is passed several times between the slabbing rollers, end or sidewise, according as it may appear to require distension, until sufficiently reduced in thickness for the finishing rollers, to which it is transferred for further distension. If the iron requires it, the slab is reheated and passed between the slabbing rollers a second time, in its reduction to a suitable thinness for the finishing rollers. These are made of the hardest iron, and turned to a glassy smoothness on the surface. At first its direction between the finishing rollers is regulated to supply any omission in the slabbing: the object being to assimilate its horizontal proportions to those of the intended plate. When this is accomplished, it is passed successively in the same direction until the desired thinness has been attained. Metal gauges of the length, breadth, and thickness of the plate, indicate when the rolling is to be discontinued. The shearing to the exact size is performed on the cold iron by powerful lever-shears, with steel knives five or six feet long.

The manufacture of common boiler plates, ship-building plates, and much of the inferior descriptions of sheet-iron, is conducted in a different manner.

The puddle-ball of the boiling-furnace is hammered into a flat bloom, two of which are placed together to constitute the plate; when cold, they are chargéd into a furnace, heated to melting, slabbed, and rolled in the foregoing manner to the desired thinness. Plates made in this manner, however, ought never to be used in any description of boiler building. A very general recourse to this mode of manufacturing has unquestionably lowered the character of boiler plate-iron, and led to many fatal explosions. Good boiler-plates should not break with a less strain than twenty five tons to the square inch of metal; but much of what is manufactured for the purpose will not bear more than two-thirds of this strain.

Nail Rod Iron.

Nail rods are manufactured in two ways: by rolling a bar down to the desired section; and by cutting a thin strip of iron into a number of parallel rods, by means of revolving shears. The first method is pursued with iron for horse-shoe nails, and the superior kind of rods, forming about two per cent. of the manufacture; and the shearing with the remaining ninety-eight per cent.

The manufacture by shearing strips, is known in the trade as slitting nail-rods. A slitting-mill consists of two or three heating furnaces, a pair of grooved rollers for roughing the pile, a pair of smooth chilled-iron rollers for flattening it, and a pair of revolving shears, with the requisite lever-cropping shears. Rollers and shears are commonly placed in parallel lines, seventeen or eighteen feet apart, and driven at nearly the same number of revolutions per minute by strong spur-gearing. The shears are formed of two parts, each consisting of a number of discs of wrought-iron, sixteen or seventeen inches diameter, edged with steel, kept the requisite distance apart by other discs of iron of lesser diameter; the whole firmly bolted together, and mounted on a cast or wrought-iron spindle. When revolving, the upper series of steeled discs project into the spaces of the lower series (see fig. next page), thus forming a number of continuous shearing edges. The depth which they project is regulated by screw-bolts attached to the cast-frames; while the entrance of the iron to be shorn is regulated by guides and plates, similarly adjusted by screw-bolts. Through the bottom of a cistern at top, a shower of water falls on the steel, to keep it from softening with the heat of the bars. In front of the apparatus a wrought-iron grated frame is constructed of iron bars, to receive the rods delivered by the shears.

The mode of rolling may be described thus: Two or three pieces of puddle-bar, or other flat iron, are placed to form a low pile, which is brought to a welding-heat in a reverberatory furnace, and transferred to the grooved rollers. In these it is distended to a bar ten or twelve feet long, by three and a half or four inches wide, and of a thickness proportionate to the size of the intended rod. It is now passed between the smooth rollers, so as to reduce it to the precise thickness, and at the same time remove any roughness on the face of the iron. It is now of a width somewhat less than the breadth of the upper series of steeled discs; and on inserting one end of the strip between

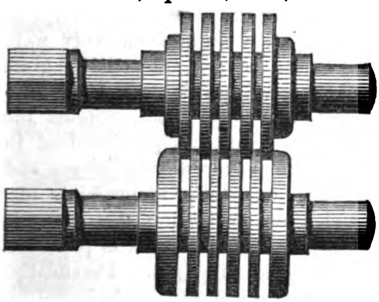
the guides, it is drawn on by the revolving shears, and cut into as many rods as there are steeled discs in its width. The divided rods are secured on light hooks, and transferred to the grating. The strips vary slightly in width; and when such is the case, or the iron is of a weak red-short character, a number of imperfect rods are shorn off the sides, and passing aside the guides, require constant cleaning from the apparatus.

The finished rods are cut to length, weighed into bundles, and tied up by twisting around them three or four small bands of hot iron. If placed in stock, or in carriages for conveyance to purchasers, great care should be taken that they do not get wet and rusted on the surface. Rods prepared by shearing may readily be distinguished from rolled rods by the concavity of the one and convexity of the opposite side; the other two sides also show the cutting action of the shears, and two edges project slightly with minute serrations.

The rapidity with which nail-rods are produced by this process is perfectly marvellous to the uninitiated. Working on the smaller sizes of rods, a mill rolling three lengths at once, as is now generally done in the larger mills, delivers ninety to a hundred rods at each operation, equal to the continuous delivery of a single rod through the week at a velocity of ten miles per hour.

Hoop-iron is manufactured from small piles or billets, rolled first between small rollers having grooves on their circumference, and lastly between a short pair of hard cylindrical rollers, in which it is pressed to the width and thickness desired. The great length of the bars, and their tendency to cool quickly, renders it necessary to propel the grooved rollers at very high velocities; but the smooth pair are driven at the more usual speed of ninety or a hundred revolutions per minute. This pair requires to be exceedingly strong, in order that the iron may be finished comparatively cold, and thereby carry a blue face.

Small flats, squares, bolts, and fine irons generally, are rolled with trains having three rollers in height. The addition of a third roller to each set expedites the rolling one-half, inasmuch as the operation is continued in both directions, instead of returning the bar over the top roller as in large mills. The rollers are commonly eight or nine inches in diameter; the roughing set thirty inches long, the second twenty-four, and the finishing nine inches long: three rollers in height, instead of the two in other mills. A speed of 230 revolutions per minute is common, and preferable to slower working; at this velocity the periphery of the roller moves over six miles per hour; and calculating the several movements of the operatives in following the bar through the day, it is seen that several of them walk more than twenty miles daily at this quick rate.



Circular Cutters for Nail-rods.

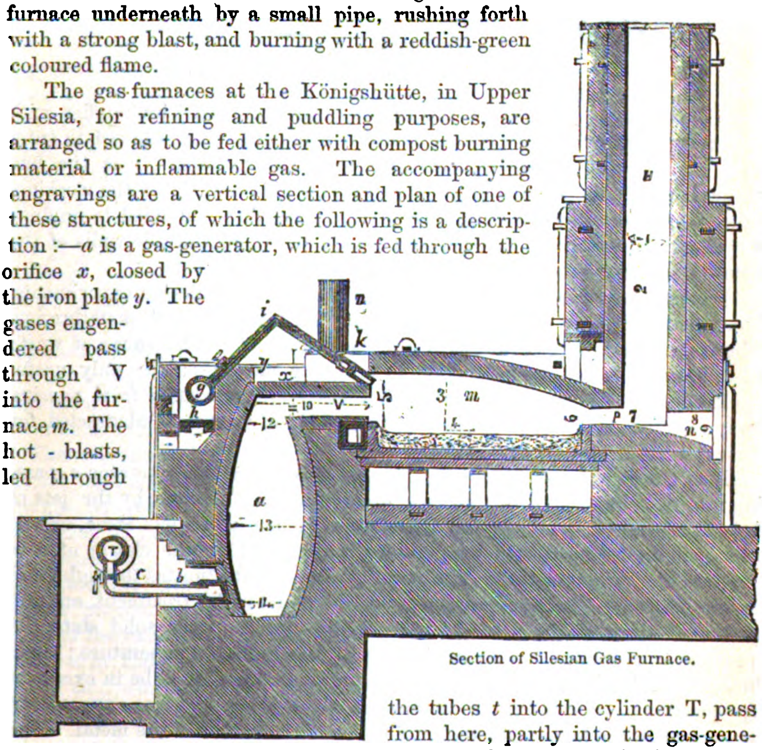
The rolling of small flats and squares in such trains is conducted on principles similar to those pursued in larger mills; but the round iron is rolled with the assistance of double guides. Small piles, or solid pieces of iron termed "billets," are roughed between the first pair of rollers; in the second the iron is first converted to a square, and then into a bar of an oval section, precisely equal in area to that of the intended round bar. The grooves in the short finishing-rollers (of which there are only two in rolling rounds) are of an exact semicircular shape, and together form a complete circle. The oval bar is presented to these rollers, guided in a vertical direction by closely-fitting iron blocks, where it is violently compressed to a perfectly cylindrical form. To ensure this being done, there must be a rigid correspondence between the oval and circle. If the oval is too small, the deficiency of metal to fill the circle is seen in the flattened sides of the latter; if too large, the excess of metal is frequently forced out at the sides, forming thin flanges. If the guides fail to hold the bar sufficiently tight to prevent its turning around, the bar is similarly spoiled. As may be imagined, it is only very good iron that will stand the violent alteration of structure when comparatively cold.

Gas Refining Furnaces.—Several attempts have been made to introduce gaseous fuel into smelting and puddling operations; but hitherto with indifferent success in this country. It seems to us, looking theoretically at the question, that if combustible gases are generated from the solid fuel and applied to such purposes, that is accomplished by a complicated process which can be more advantageously attained by using the fuel itself. The chemical world, however, is not well informed on this subject; and we wait with much interest for Mr. Abel's report to the Minister of War, of the result of his investigations into the gas furnaces, and other refinery processes in use in Upper Silesia, Prussia, and the Austrian iron-works, which are said to be at variance with our conclusions. Reasoning, however, from our present imperfect information, if we would produce the highest heat from fuel, all its carbon must be converted into carbonic acid, which is done in every well-constructed furnace with brick walls, where the layer of coal on the grate does not exceed seven inches for bituminous coal and eighteen for anthracite. Combustion thus conducted, it is practically found, obtains the greatest heat and the largest quantity of it. The principle involved in forming gas, is to use a thick layer of coals, and convert all the oxygen and carbon into carbonic oxide; introducing fresh oxygen or atmospheric air, at a proper place behind the grate, and thus converting the carbonic oxide into carbonic acid. If perfect combustion of solid fuel is produced in the grate, as much heat is obtained as in forming gas. Practically, indeed, it is stated that in well-constructed furnaces there is less fuel used by burning it directly than is required in generating gas. In the case of reverberatory furnaces, the use of gas is inconsistent with sound principles—flame is there required; but by forming and burning carbonic oxide, no flame is produced, and radiation of heat cannot be expected.

Thoma has, however, recommended the employment of the gaseous results of the combustion of coal, wood, and turf, as a fuel for smelting iron; and in

Scotland, and also in Norway, the experiment has been tried of employing hydrogen for this purpose, conjointly with the hot-blast, with the result, it is stated, of a high rate of combustion and diminished waste of fuel. In the iron-works of Brefens, at Orebroe in Norway, the hydrogen was developed in a system of thirty-two tubes, heated on one side of the furnace, and placed in communication with four other horizontal tubes of double the dimensions of the first. The thirty-two tubes are arranged in four rows; they are charged with light wood-charcoal, and steam is made to pass through them, having in its course to traverse a considerable distance. The steam generator, which is cylindrical in shape, is placed over the flame, and the water-level is kept even by means of a force-pump. At the extremity of each tube is a screw-stopper, which, being removed, permits of the ashes being cleaned out or a new charge introduced. The results of mutual decomposition are hydrogen, carbonic oxide, and a little carbonic acid gas, which are transmitted into the furnace underneath by a small pipe, rushing forth with a strong blast, and burning with a reddish-green coloured flame.

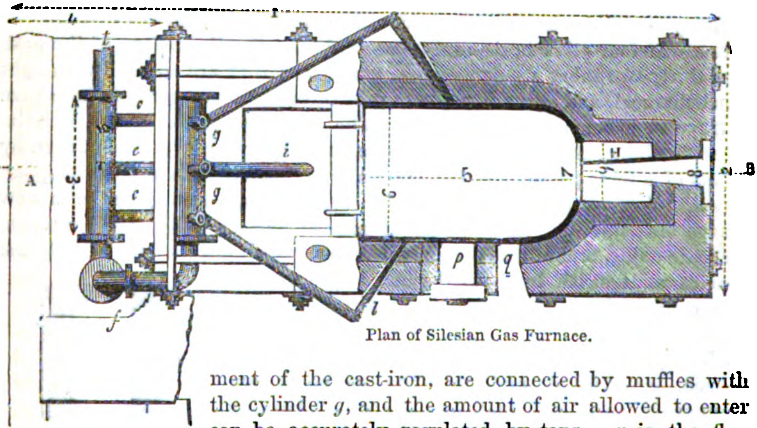
The gas-furnaces at the Königshütte, in Upper Silesia, for refining and puddling purposes, are arranged so as to be fed either with compost burning material or inflammable gas. The accompanying engravings are a vertical section and plan of one of these structures, of which the following is a description:—*a* is a gas-generator, which is fed through the orifice *x*, closed by the iron plate *y*. The gases engendered pass through V into the furnace *m*. The hot-blasts, led through the tubes *t* into the cylinder T, pass from here, partly into the gas-generator *a* and partly into the furnace *m*.



Section of Silesian Gas Furnace.

The blast passes through the tube *c* into the sheet-iron box *b*, and thence through two tuyeres *d* into the gas-generator. The other portion of the blast

passes through the tubes *f* into the cylinder *s*, thence through the tubes *i* into the box *k*, and then into the furnace in strong puffs. The heat can be further increased by the auxiliary grate *h*. The tuyeres *l*, which aid the refine-



Plan of Silesian Gas Furnace.

ment of the cast-iron, are connected by muffles with the cylinder *g*, and the amount of air allowed to enter can be accurately regulated by taps. *r* is the flue through which the burned gases pass into the chimney H. *p* the working-hole. *g* the running opening. *u u* are cast-iron flues, intended to produce a violent draught under the cast-iron hearth and along the side walls of the furnace, in order to cool it.

We are without information as to the results of the Silesian experiments, but believe we only echo the opinions of the best practical metallurgists when we state that gas, unless it can be drawn off in the shape of waste heat, cannot be profitably applied to smelting purposes: the only useful application of gaseous fuel is when hot gases are prevented from passing away into the air, and their heat, instead of being wasted, is abstracted for some useful purpose.

It might be well to mention that the hot gases from the generator *a*, passing into the chamber of the furnace, are ignited to whiteness by the jets of hot-blast *i* and *l l*. The tuyere pipes from whence these jets issue, are so arranged that a maximum temperature is produced on the charge of iron opposite the working door P. The quantity of hot-blast admitted through these tuyeres is adapted to the requirements of the metal under treatment, and the particular stage of the process. When the iron is in the solid state, the quantity is regulated to the production of the highest temperature; after fusion, decarbonization of the pig-iron requires that it should be in excess of the quantity necessary for the combustion of the gases, that free oxygen may be present in the furnace for the combustion of the carbon of the metal. The alloyed carbon having been burnt off, the quantity admitted is again reduced to the proportion necessary for the combustion of the hot gases, and the balling up of the iron completed.

Puddling with gas is practised to a limited extent in Rhenish Prussia. In some few instances the gas is taken from the blast-furnace, but more frequently it is generated in the small ovens attached to each puddling furnace; the fuel used in the distillatory process consists of dry wood, charcoal, lignite, or turf. At an iron-work where wood is used, the charges are eight cwts. of white and mottled iron, and each furnace brings out twenty to twenty-one tons of puddle-bars per week, with a loss in the working of five per cent. on the quantity charged. The consumption of timber is about four cubic feet for one cwt. of puddle-bars.

At a second works, the charge consists of ten cwts. of gray pig-iron, which is two and a half hours under treatment in the furnace, with a corresponding reduction of yield or produce. The timber consumed, cord-wood, averages nearly nine cubic feet for one hundredweight of puddle-bars. Puddling with the gas of lignite is also carried on experimentally.

Although turf, lignite, and fine cones have been experimentally used for generating the gas, the preference seems to be given to wood; and with the foregoing data, a comparison may be drawn between the relative commercial advantages of coal and gas fuel in English puddling furnaces. The selling price of cord-wood, of the kind used in the mines of this country, averages twenty shillings per ton, or sixpence the cubic foot. With the minimum consumption of four cubic feet of wood to the hundredweight of bars, the cost would be two shillings; whilst with the larger consumption of nine cubic feet, it would amount to four shillings and sixpence for each hundredweight of bars produced. Bituminous coals of the description commonly used in puddling, cost about eight shillings per ton: the consumption of a mixed charge of pigs will not exceed twenty hundredweights to the ton of puddle-bars produced. Hence, the cost with coal-fuel will be about five-pence to the hundredweight of puddle-bars. Contrasting this with the former estimate, it is seen that while in England coal-fuel for the production of a stated quantity of bars costs five-pence, the gas fuel of wood cannot be substituted at less than from five to eleven times this sum.

The comparative barrenness of the German metallurgical districts in mineral fuel, and the generally inferior quality of the small deposits being wrought, has resulted in considerable attention being paid to the economical application of gases in puddling. It is doubtful, however, if there be any advantages from its use, except in special cases, or where, from its great abundance, the timber is held to be of little value in comparison with that of superior pit-coal. Certain it is, that the use of wood fuel in puddling, indicates the existence of the manufacture on a small scale compared with its condition in England, where the quantity of standing timber in plantations, forests, &c., would scarcely suffice for the wants of the puddling furnaces (nearly 3500 in number) during a single year.

CHAPTER XIV.

RECENTLY PATENTED REFINING PROCESSES.

We now come to deal with a class of metallurgic processes which have recently much occupied the public attention—an attention which their importance fully justifies. We allude, of course, to the processes patented or otherwise having for object the conversion of ordinary cast-iron into malleable iron, by the application of air, or air and steam combined, without the intervention of fuel. We cannot but regret that the necessity for consecutive publication compels us to take up the subject in its present unsettled state, as we hoped to have communicated more exact information on these important inventions than is at present attainable.

The reader who has attentively followed our account of the processes by which iron has hitherto been converted, must have been struck with the laborious character of the whole series of operations; more especially, when he considers the gigantic efforts required on the part of the workmen in the puddling and refining processes, will he be roused to the importance of any discovery by which even a portion of this laborious operation can be dispensed with. Nor when the economical considerations which enter into the question are borne in mind, will it surprise him that the change in the iron manufacture, which it was presumed would at once follow the announcement of Mr. Bessemer's discovery, should have created an excitement almost amounting to a panic in the principal iron districts. It was not in the nature of things, however, that such startling and rapid changes should at once develop themselves in perfection; the process, therefore, although watched with much interest by those interested, is at present only felt to be a step in advance of the older processes, which will be welcomely received, should the experiments now preparing on a large scale fulfil the expectations entertained of it. The inventions to which we have alluded we shall take in their chronological order, beginning with the earliest of them, namely—

Mr. Plant's Process.—Of this process no specification has been published; we must, therefore, avail ourselves of the condensed report given of it in the "London Journal of Arts." The patent is dated July 18, 1849; in it the patentee claims to have made an improvement in making bar-iron by the use of either hot or cold blasts, with steam-jets and atmospheric air, or with steam-jets by themselves, to be used in regulating the heat in the puddling-chambers, either with the ordinary damper in the draught of the chimney, or with a special damper and apparatus adapted to his invention.

This apparatus consists of a puddling-furnace of ordinary dimensions, having three lines of tuyeres across the top of the furnace, each line consisting of three tuyeres one inch in diameter; the line furthest from the chimney being for the blast, the other two being steam-tuyeres for the puddling and

preparatory chambers. The blast-tuyeres are to be capable of a pressure of one pound and upwards to the square inch; the steam to be used at a pressure of ten pounds and upwards.

The blast is to be introduced at the top of the puddling-chamber, in a slanting direction, just behind the fire-bridge, so as to draw the flame down upon the whole surface of the metal as it enters the puddling-chamber; the steam being introduced as nearly as possible at the same spot, and thrown in like manner upon the whole metal.

By these means, it is stated, the heat of the furnace and preparatory-chambers can be regulated with great nicety, without employing the damper usually inserted in the chimney of a puddling-furnace. When the metal is melted, the blast is shut off, and steam introduced through the tuyeres until the iron boils; the steam is then turned off and the blast brought into action till the iron appears above the cinder, when the blast is again shut off and the iron finished in the usual manner by the ordinary draught. The heat of the puddling-chamber is raised or lowered from time to time by raising or lowering the damper over the fire-bridge.

In this process, a greater separation of the metal is caused, it is presumed, by the blast of air and jets of steam thrown *upon* the metal; and the carbon and other impurities are supposed to be more thoroughly removed by the infusion of the oxygen of the atmosphere.

Martien's Process, to which we shall now call attention, is that patented by Joseph Gillot Martien, of Newark, New Jersey, in September 1855, and has for its object the purification of iron when in the molten state from the blast or refining-furnace, either by air or steam, or vapour of water applied from below, so that it may rise up amongst, and completely penetrate and search every part of the metal previous to congelation, and prior to its being run into a reverberatory-furnace for puddling. By this means the manufacture of wrought-iron by puddling, and the manufacture of steel from cast-iron in the ordinary manner, are stated to be greatly improved.

In carrying out his invention, Mr. Martien employs channels, or gutters, so arranged that the numerous streams of air, of steam, or of vapour of water, are passed through and amongst the melted metal, as it flows from the blast-furnace. This is done by subjecting the metal to the action of streams of air or steam, as it passes from the blast-furnace before it congeals. The apparatus recommended, consists of cast-iron channels or gutters, having the bottom made hollow to receive steam or air, or both. This gutter is perforated with numerous holes, obliquely inclined in the direction of the flowing metal, so that the streams of air or steam may be forced through it as it flows along the gutter. The stream of air, however, may also be passed up through the metal; or the holes may be inclined in the opposite direction, so as to oppose the flow of the molten metal. When the hot or cold-blast is used, the hollow bottom of the gutter may be connected with the air-pipes used for supplying the blast; or, when steam is employed, the gutter may be connected with the boiler. By these means, the air or steam introduced rises up through the metal in numerous streams, and the iron is stated to be perfectly purified

after it has come from the blast-furnace, and before congelation takes place. The iron thus purified may be allowed to cool in the mould, or it may run from the gutter into a reverberatory or other refining furnace, to be heated and puddled in the usual manner. In this process, the novelty claimed is that of purifying iron from a blast-furnace while still in a molten state, without the intervention of fuel; thus preparing it for the puddling process in a state of greater perfection than by the old process. The perceptive faculties of James Nasmyth, to use the words of Mr. Bridges Adams, the eminent civil engineer, "detected the absurdity of setting a number of human beings to stir up a metallic pudding in order to throw off the scum in the shape of slag or cinder. His remedy was a mechanical one—to cause the mass to boil like a pot, by forcing steam into it from below, the issue of steam beginning before the molten mass was poured in, so as to insure against the stoppage of the passages. But steam is not exactly fuel, and, instead of increasing, tends to lower the temperature of the mass of iron."

Mr. Clay's Process.—Among other ingenious inventions, we may here mention that of Mr. Clay of the Mersey Iron Works,—an invention for which a patent was taken out and a specification lodged, as applicable both to malleable iron and cast steel; although all claim for the latter purpose has since been withdrawn in favour of Captain Uchatius' process. Mr. Clay proposes to refine the crude iron by a process of granulation, produced by dropping iron in a molten state from a lofty tower into a water-tank, after the manner in which small lead-shot is cast. In this process, he states that the highly separated metal is purified by contact with the air in its lengthened descent, and by the chemical change produced by immersion in the water, so that, when again melted for the puddling furnace, it is divested of most of the impurities of crude iron.

For the purposes of this invention, iron may be obtained either from the blast-furnace, from which it may be run out in a molten state, or it may be melted down from pig or scrap cast-iron. The granulation of the iron is effected by causing the metal, when in a molten state, to run through a perforated plate of metal or other material, placed at the top of a tower-shaft or well; by this means it will be divided into small shot-like particles. In its descent in this state from a suitable height, varying according to the nature and quality of the iron operated upon, the metal will, during its passage through the air, be partially decarbonized, inasmuch as the oxygen of ordinary atmospheric air acts with considerable force in decarbonizing the metal as it falls through it; it will thus be rendered more suitable for working up by puddling into malleable bar-iron.

It is sometimes advisable to charge the air in the shaft, through which the molten metal is to pass, with artificially prepared oxygen, or with some other decarbonizing gas or vapour, which will produce a more vigorous decarbonizing action upon the iron. This may be effected by the decomposition of the salts of potash, such as chlorate of potash, or nitrate of potash, both of which contain considerable quantities of oxygen; and their decomposition may be effected either by dropping the red-hot metal, in a granulated or finely-divided state,

upon a bed of the salts of potash, or by heating the salts in a retort until oxygen is given out. Other minerals, also, such as manganese, may be employed, either alone or in combination with other substances, as oxygenating agents. The patentee also employs the more simple means of increasing the oxygenizing powers of atmospheric air, by introducing a blast or draught of air, either hot or cold, as may be found most effective, into the tower down which the iron is descending. Dry steam may also be applied to effect the object in view.

Mr. Clay has found that by allowing the molten metal to fall through the air a distance of about seventy feet, a satisfactory result has been obtained; this, however, depends both upon the quality of the iron and upon the state of preparation in the shaft. With atmospheric air at the ordinary pressure, the metal requires to fall through a greater distance, than if charged with the artificial means above referred to. The granulated particles of molten iron may either fall into water at the bottom of the tower or well, or they may be collected in a vessel or reservoir placed for the purpose.

The decarbonized metal thus obtained, it is scarcely necessary to add, is collected together and remelted into ingots or bars, preparatory to undergoing the ordinary treatment of hammering and rolling.

Mr. Bessemer's Process.—We have now to speak of that process of Mr. Bessemer's, which has arrested so much attention, even of the ordinary reader, in the last few months. Mr. Bessemer's first patent is dated January 4, 1856. Others he has since taken out bearing date February 12, May 15 and 31, 1856. To the most complete of these, namely, that of February 12, 1856, we shall direct our attention. In the specification now before us, the invention is said to consist in the decarbonization and refinement, in whole or part, of the crude iron, which is either obtained in a fluid state from the furnaces in which the iron ore has been reduced, or in the decarbonization and refinement of crude pig or finery iron, by remelting the pigs in a suitable furnace so as to obtain fluid metal capable of being treated by the process we are about to describe. This consists, firstly, in running the fluid iron from the furnace into a close or nearly close vessel or chamber, formed of iron, perforated with openings to receive the tuyeres, and lined with fire-brick or other material which is a slow conductor of heat. When this vessel is almost half filled, numerous small jets of atmospheric air, or gaseous matter capable of evolving sufficient oxygen to cause combustion of the carbon of the iron, are forced into and among the fluid metal, either in a cold or previously heated state. "Atmospheric air or oxygen is thus introduced into the metal, in sufficient quantities to produce a vivid combustion among the particles of the fluid metal; and to retain and increase its temperature to such a degree, that the metal will continue fluid during its transition state from crude iron to that of cast steel or malleable iron without the application of fuel."

Mr. Bessemer stated in the paper with which he ushered his invention to the British Association, that for the last two years his attention had been almost exclusively directed to the manufacture of malleable iron and steel, in

which, however, he had made but little progress until within the last eight or nine months. The constant pulling down and rebuilding of furnaces, and the toil of daily experiments with large charges of iron, had already begun to exhaust his stock of patience; but the numerous observations made during this very unpromising period all tended to confirm an entirely new view of the subject, which at that time forced itself upon his attention—viz., that he could produce a much more intense heat without any furnace or fuel, than could be obtained by either of the modifications hitherto used, and consequently not only avoid the injurious action of mineral fuel on the iron under operation, but at the same time avoid the expense of the fuel. Some preliminary trials were made on from 10 lb. to 20 lb. of iron, and, although the process was fraught with considerable difficulty, it exhibited such unmistakeable signs of success as to induce him at once to put up an apparatus capable of converting about 7 cwt. of crude pig-iron into malleable iron in thirty minutes. With such masses of metal to operate on, the difficulties which beset the smaller experiments entirely disappeared. On this new field of inquiry, he set out with the assumption that crude iron contains about five per cent. of carbon; that carbon cannot exist at a white heat in the presence of oxygen without uniting therewith and producing combustion; that such combustion would proceed with a rapidity dependent on the amount of surface of carbon exposed: and, lastly, that the temperature which the metal would thus acquire, would be also dependent on the rapidity with which the oxygen and carbon were made to combine, and consequently that it was only necessary to bring the oxygen and carbon together in such a manner that a vast surface should be exposed to their mutual action, in order to produce a temperature hitherto unattainable in our largest furnaces. With a view of testing practically this theory, he constructed a cylindrical vessel of three feet in diameter and five feet in height, somewhat like an ordinary cupola furnace, the interior of which was lined with fire-bricks, and at about two inches from the bottom of it five tuyere-pipes were inserted, the nozzles of which were formed of well-burnt fire-clay, the orifice of each tuyere being about three-eighths of an inch in diameter; they were so put into the brick-lining (from the outer side) as to admit of their removal and renewal in a few minutes when they were worn out. At one side of the vessel, about half way up from the bottom, there is a hole made for running in the crude metal; and on the opposite side there is a tap-hole stopped with loam, by means of which the iron is run out at the end of the process.

The apparatus by which it is now proposed to carry out this process, differs somewhat from that described above: it is a cylindrical vessel, mounted on axes *not* placed at the centre of gravity. Of this vessel, Fig. 1 is an end elevation. The vessel is formed of stout plates, secured by angular iron flanges to the cast-iron plates *a'*, strengthened by webs or ribs of iron. *c c* are iron frames secured by bolts *d* to the masonry, or foundation on which the operation rests. The frame *c'* rises higher than the others, and has plummer-blocks *e e* bolted to it, on which the shaft *f* revolves. A worm-wheel *g* is keyed firmly on to the axis *b*, and receives motion from the worm

h when moved by the handle *i*. At the point of junction of two of the webs *a*, will be seen a boss; into this boss a stud is fixed, to which a chain, or tension-rod, may be attached, suspended over a pulley from the roof, for supporting a counterbalance weight, so as to facilitate the movement of the vessel on its axis, and assist the worm-wheel gearing *g h*.

The intention in having the refining vessel thus mounted on axes, is the convenience it offers for pouring out the fluid metal into the ingot-mould, for which purpose it is furnished with a lip or spout, which is placed in a line with the mould, the latter being kept in a proper position for removing the fluid contents. The air, or other gaseous matters, which are to operate on the metal, must be compressed with a force greater than will balance the weight of a column of fluid metal of a height equal to the depth of immersion of the jets below the surface of the fluid metal. This air, as will afterwards be shown, is introduced at the sides or ends of the vessel, through small holes formed in the fire-clay lining; so that, by moving the chamber on its axis, the holes in the fire-clay may be made to descend beneath the surface of the metal, or raised above it as may be desired.

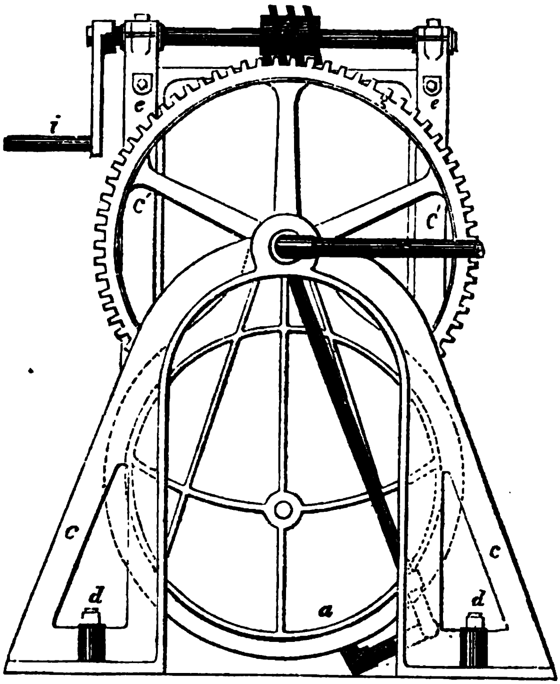


Fig. 1.

In Fig. 2 is represented a longitudinal section of the converting vessel, in order to give a more correct idea of its construction. The section presents, at one side of *a′* and at a point beyond the outer edges, the bosses *a′*, which are bored out truly, and fitted and keyed to the axes *b b*; and on these the vessel is made to move when turned by the worm-gearing *g h* (Fig. 1). At *r* there is a pipe which communicates either with a blast-engine or steam-boiler, or it

may be made to communicate with a reservoir of oxygen gas, or any other gaseous matter capable of evolving oxygen, either in a cold or heated state. The pipe *r* is fitted to one end of the trunnion or axis *b*, which is hollow, and

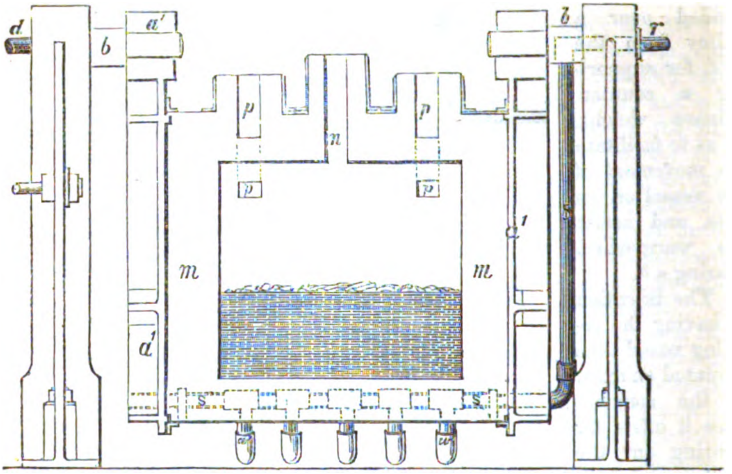


Fig. 2.

provided with a stuffing-box, or other joint, so as to allow of the movement of the axis without interfering with the passage of the air or other matters through it. This pipe is continued to S, and along the outside of the vessel S, where it requires to be turned truly on its exterior surface, having fitted to it several small branch-pipes *u*, each of which has a T piece connected to it, which is bored out truly, so as accurately to fit the exterior of the pipe S; thus admitting of the pipe *u* being moved on the pipe S into its proper position. The object here, is to connect the blast-engine with the converting vessel, along one side of which there is a row of square holes: into these, small blocks of well-burnt fire-clay are closely fitted, and held in position by ramming a little loam into the joint formed between them and the lining *m*. At one of these blocks or tuyeres, the pipe *u* is fitted by a simple cone joint, the other ends of the tuyere-blocks having several small perforations leading into one larger passage communicating with the pipes *u*; a communication is thus established between numerous points of the interior surface of the converting vessel, and the blast-engine or other apparatus used. A sluice-cock on the pipe *r*, enables the workman to turn this off or on as required.

The manner in which these pipes and tuyeres act will be better understood by the following engravings, where Fig. 3 represents a section of the pipe *u*, and the mode of fitting it into the pipe S; while Fig. 4 shows them in their ordinary working position. It will be seen by Fig. 3 that the

pipe S has an opening at x opposite the orifice of the pipe u. When these pipes occupy their ordinary position, as in Fig. 4, the air passes freely through the opening; but when the tuyere-blocks require renewing, the pipe u can be turned upon the union joint formed at the junction x: free access to the tuyere is thus obtained. The manner in which these pipes act upon the metal in the converting vessel is shown in Fig. 5, and again in Fig. 6.

The tuyere-blocks may be formed of one or of several smaller apertures, one being found to answer perfectly well in practice; they must, however, be made to fit exactly into the pipe. These passages sometimes get obstructed; to provide for this, a screw-plug (Fig. 3) is fitted at the back of the elbow of the pipe u, which may be removed if necessary, and a steel rod thrust through the aperture, so as to remove any accumulations of matter.

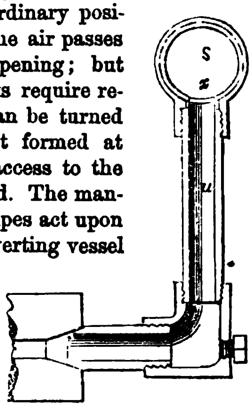


Fig. 3.

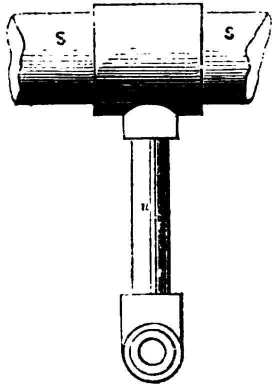


Fig. 4.

The interior of the converting vessel itself is lined with fire-brick or fire-stone, as shown at m (Fig. 2); and arrangements are made by which this lining may be renewed or repaired either by removing one of the end plates a', which can be bolted on again; or a man-hole may be devised in the side of the vessel through which the lining may be repaired without this removal. The peculiarities of the vessel itself we shall now describe; and in order to convey a correct idea of it, we give two

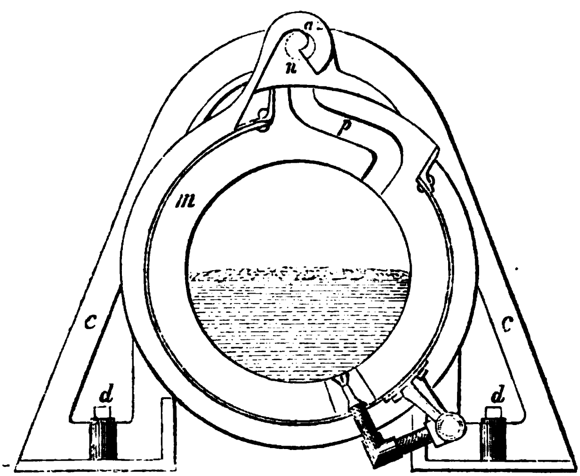


Fig. 5.

illustrations (Figs. 5 and 6): one a vertical section, exhibiting the vessel while the metal is in a molten state, with the tuyeres in full operation; the other, a similar section, where the fluid metal is presumed to be purifid, and in the act of being poured out into the moulds and formed into ingots. In each of these sections the peculiar lip-like form of the spout *n* of the vessel is shown; this projecting spout is for the purpose of running out the fluid metal, and is made to project from the vessel so far as to bring it in a line with the axis, so that into whatever position the vessel *a* may be moved, the extremity of the lip *n* may retain the same position, or nearly so; thus allowing the stream of metal flowing over it to fall into the ingot-mould.

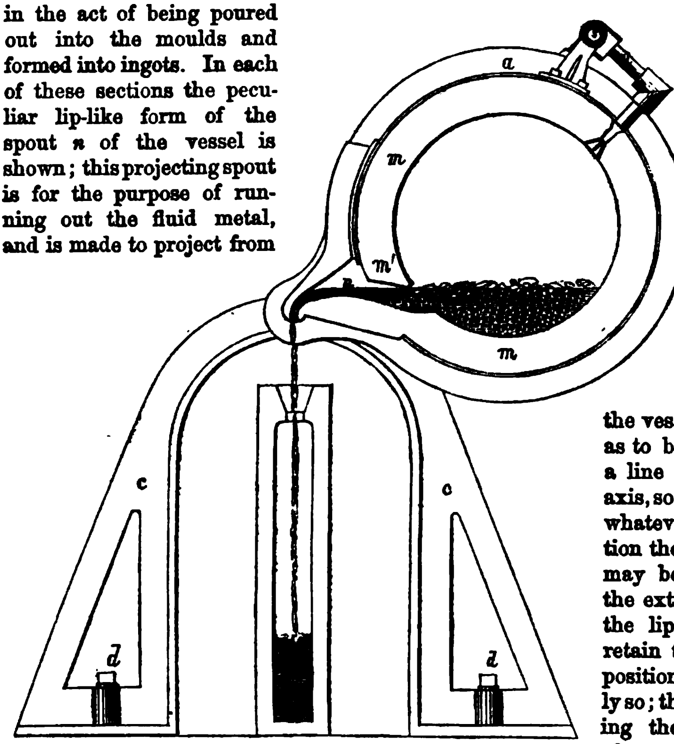


Fig. 6.

By reference to Fig. 6 it will be seen that at *m'* the lining is formed so as to prevent the slag, and other impurities floating on the surface, from flowing out until after the metal itself has run out. On each side of the spout *n* there is a curved passage *p* (Fig. 5), by means of which the flame and gaseous products evolved during the process may escape; but the plashes of the metal thrown up by jets of air are, for the most part, prevented from escaping by the serpentine form of these outlets in the converting vessel.

Having thus minutely described this apparatus, let us follow its author through the process. When the chamber is about half-filled with fluid metal drawn from a smelting or remelting furnace, atmospheric air, either in a cold or heated state, or gaseous products capable of evolving combustion of

the carbon contained in the iron, is blown or forced into and among the fluid metal; and this is found sufficient to keep up the required temperature during the process.

The size and number of jets or tuyere-pipes required for this purpose, vary according to the quantity of metal operated upon at a time, and also with the condition and quality of the metal; thus forge, pig, or refined plate metal will not require so much oxygen to complete its carbonization and conversion into malleable iron, as is required for the conversion of crude iron of the quality known as No. 1 or No. 2 foundry-iron. To these qualities of metal a tuyere is required having an outlet larger by about twenty per cent. than is used for the white qualities of iron. The patentee hesitates, however, in giving any fixed rule where so much depends upon the force or pressure of the blast, and the quality of the iron, preferring to give the following example from his own practice, as a guide to the workmen. "When using foundry-iron of the quality No. 2," he says, "I run one ton into the converting vessel, in which it rises to the height of about a foot above the orifices of the tuyere-pipes; and then force into the fluid metal, atmospheric air in its natural state, under a pressure of about 10 lbs. to the square inch, employing from six to twelve tuyere-pipes for its distribution, the united area of the pipes being two square inches. The quantity of blast admitted by this area of inlet, will in general be found sufficient to effect the conversion of the crude iron into a malleable condition in about thirty minutes. Where a mixture of oxygen gas with atmospheric air or steam, or steam alone; or where other gaseous fluids capable of evolving oxygen are preferred in lieu of atmospheric air; then the size of the tuyere-pipes should be regulated according to the quantity of oxygen present, diminishing the area of the pipes where the oxygen is in excess, and increasing the area where the quantity is short of the above proportion."

When the vessel is new or newly lined, it may be heated by the waste gases of the blast-furnaces, or any other convenient means, previous to the crude iron being poured in. The patentee sums up the substance of his discovery in the following terms:—"It is well known that molten crude iron, under ordinary circumstances, will soon become solidified unless a powerful fire is kept up, and is applied direct to the fluid metal, or to the exterior of the vessel containing it. It is also well known that if the quantity of carbon which is usually associated with crude iron is diminished, that the temperature necessary to maintain its fluidity also rises in like manner, so that when iron has lost the whole or the greater part of its combined carbon, the metal can only be kept in a fluid state by the heat of powerful furnaces; but I have discovered that if atmospheric air or oxygen is introduced into the metal in sufficient quantities, it will produce a vivid combustion among the particles of fluid metal, and retain and increase its temperature to such a degree that the metal will continue fluid during its transition from crude iron to the shape of cast steel or malleable iron without the application of fuel, the high temperature being obtained by the oxygen uniting with and causing a combustion of the carbon in the crude iron, and by the combustion of small portions of the iron itself."

As a matter of convenience, the patentee suggests, while reserving his right to apply modifications of the apparatus described, that the converting vessel should be placed near to the discharge-hole of the blast or remelting furnace, from which the crude iron is to be drawn; that the interior of the chamber should be heated by burning gases, or by introducing wood-charcoal or coke at the passages *p* (Fig. 5); and that a blast of air be turned on through the tuyere-pipes, by which their combustion may be kept up and the vessel dried before turning the crude metal into it. For this operation the vessel is placed in the position shown by Fig. 5, having a moveable gutter leading from the tap-hole of the smelting furnace into the upper end of one of the passages *p*, the tuyere-pipes being now in operation. As soon as the metal covers the orifices of the tuyere-blocks, a violent ebullition is produced, the air dividing into globules, and diffusing itself among the particles of fluid iron, and thus coming in contact at numerous points with the carbon consumed in the crude iron, and producing thereby a vivid combustion, while the gaseous products escape by the passages *p*.

In about fifteen minutes from the time of commencing the process, large frothy slags are thrown violently out of the passages *p*, accompanied by a rush of bright flame; after a few minutes' duration this eruption ceases, but copious flame still continues to escape by the passages. At this stage of the process the crude metal has thrown off the bulk of its impurities, and is, in all probability, in the state of cast-steel; its exact state, however, can be ascertained by turning the handle-shaft *f*, so as to bring the vessel round on its axis, as in Fig. 6, when a portion of the metal may be discharged into an ingot-mould, where it is quickly cooled and examined; if not sufficiently decarbonized, the vessel is restored to its original position, and the process continued till completed—from five to ten minutes' blowing being generally found sufficient to convert the metal from the condition of cast-steel to malleable iron. When it is necessary to suspend the operation of blowing for a short time, the vessel should be brought into a position half-way between Figs. 5 and 6, so that the orifice of the tuyere-pipes may be above the surface of the metal, otherwise the tuyeres will be stopped up with the fluid metal. The whole process of conversion from crude pig-iron No. 1 to malleable iron, occupies from thirty to thirty-five minutes, varying according to the quality of the pig; but the exact point when the process should cease, will soon be acquired by the workmen, since the colour and volume of the flame issuing from the passages vary with the condition of the metal, thus forming a good guide for the workmen; while the facility with which trial-ingots may be taken affords an infallible test.

The heat, in some cases, is so excessive that the metal, even when reduced to malleable iron, is still so far above the melting point that its temperature requires to be reduced before casting. For this purpose, the vessel is brought into the position half-way between that shown in Figs. 5 and 6, the tuyeres being above the surface of the metal, the supply of air stopped, and a fire-brick placed over the orifice of the passage *p*, so as to prevent the heat from escaping with too much rapidity. In this way the temperature

gradually subsides, and the metal is brought into a proper state for casting; or, if that is preferred, for taking out of the vessel in masses after cooling down by stirring.

We have now to deal with a part of the refining process in which it occurs to us that Mr. Bessemer has been altogether misunderstood, both by those who have criticised his inventions most severely, and by the general public. The notion generally entertained, we believe, is that by means of combustion alone, and without fuel, that gentleman professes to produce malleable iron. This is not so. He only professes to have discovered, that the rapid union of carbon and oxygen which takes place at the temperature which has now been attained, still further increases the temperature of the metal, while the diminished quantity of carbon present allows a part of the oxygen to combine with the iron, which undergoes combustion, and is converted into an oxide.

At the excessive temperature which the metal has now acquired, he continues, the oxide undergoes fusion, and forms a powerful solvent of those earthy bases that are associated with the iron. The violent ebullition which is going on mixes most intimately the scoria and metal, every part of which is thus brought in contact with the fluid oxide, which will thus wash and cleanse the metal most thoroughly from the silica and other earthy bases which are combined with the crude iron, while the sulphur and other volatile matters, which cling so tenaciously to iron at ordinary temperatures, are driven off, the sulphur combining with the oxygen and forming sulphurous acid gas: producing by this means a purer iron by the application of atmospheric air to the fluid metal than could be produced in the puddling-furnace by a large consumption of that costly material. Beyond that, the process recommended very much resembles the mechanical appliances by which malleable iron is produced by the older methods; namely, by subjecting the ingots at a welding heat to a forge-hammer or squeezer of a peculiarly powerful construction.

During the interval occupied in cooling down the boiling metal, the workman has to prepare his ingot-moulds. A convenient mode of doing this is to place them in an iron truck, mounted on wheels, which may be moved under the spout of the vessel, and passed out under the arched openings left in the furnace. The ingots thus prepared, are now in a fit state for being hammered, tilted, or rolled into bars, rods, or plates. In some cases the ingots are found to contain cells and cavities; in this case they are subjected, at a welding heat, to the action of squeezers, or they are subjected, in a suage or die, to repeated blows under a powerful hammer, so that the parts are forcibly driven together, and the cells welded before being subjected to the rolling-mill or tilt-hammer.

The squeezers, and other apparatus recommended by Mr. Bessemer, differ considerably from those previously described. The squeezer has transverse grooves, both on the upper and lower jaws, as represented in Fig. 1; A A being the grooves or hollows, B an ingot placed between the jaws. In this operation the ingot, or mass of metal, is brought to such a temperature in a

suitable furnace as will sufficiently soften it to admit of its being pressed into a solid homogeneous body.

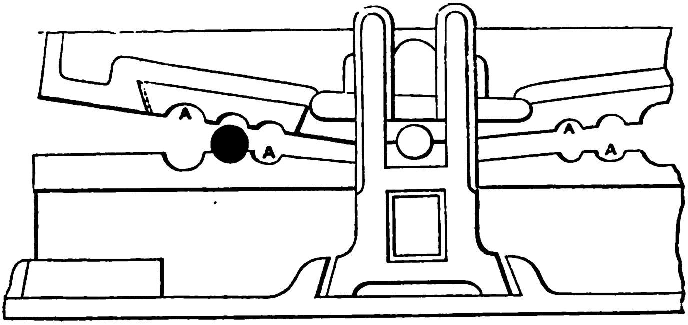


Fig. 1.

The same effect may be produced by hammering the ingot on a suage or die, as illustrated in Fig. 2, where P represents the lower portion of a steam-hammer, having a grooved block Q fitted into it; a similar block N is secured to a heavy mass of metal O, which forms the bed of the hammer; M being a wrought-iron hoop, lined with steel, which is made so as to slide up or down by means of the rods S. The workman, having heated the ingot G, holds it with a pair of tongs in the groove of the lower block, while the upper one falls upon it with such force as is necessary. By the use of these grooved surfaces, or suages, the ingot of metal is less liable to be crushed than when hammered between two parallel flat surfaces, which give no support to its sides. In this operation the workman will move the ingot backwards and forwards, turn it over on its side, and so work and compress the metal while at a welding heat, as thoroughly to solidify the iron and render it fit for the tilt-hammer or rolling-mill.

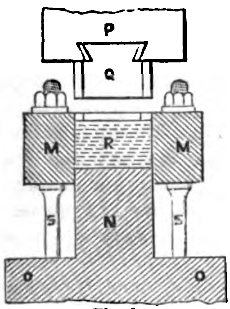


Fig. 2.

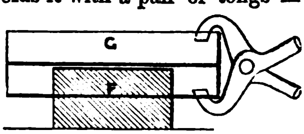


Fig. 3.

Other modifications of the steam-hammer are mentioned by Mr. Bessemer, all, however, having one principle; viz. that the ingot is placed upon a block, or anvil, supported on both sides by strong rests, while the hammer falls into the groove formed by these supports. By this means the tendency of the ingots to crush out laterally is prevented, while the metal is left at liberty to expand itself in length, thus undoubtedly encouraging the fibrous condition inseparable from malleable iron. This effect is produced by many modifications of apparatus, the details of which are unimportant, provided the dies or

suages are so constructed, and the ingot of spongy or cellular metal so confined, that when the hammer is brought forcibly in contact with it the tendency is to have its various parts forcibly squeezed, pressed, or driven together, the pores closed, and the surfaces united or welded together.

In the probationary state of these patented processes it is impossible to draw any decided conclusions as to their probable results. There is that in Mr. Bessemer's process which has strongly impressed the public mind, and which only the conviction of complete success or failure will satisfy. While the popular view has thus, sometimes with little knowledge of the subject, magnified the discovery far beyond its merits, there have not been wanting others who would divest it of any merit whatever, and treat it as altogether unworthy of serious consideration. As in most other cases, truth seems to lie between these extremes.

We have already seen that the principal impurities in cast-iron consist of carbon, sulphur, phosphorus, silicon, and some other substances of less importance. These substances, Mr. Bessemer asserts, combine with oxygen at a high temperature, forming volatile compounds, which are incapable of again entering into combination with the metal. The principle of Mr. Bessemer's process is to take advantage of this tendency of the substances to unite with oxygen. By forcing atmospheric air into the fluid metal, intense combustion is produced; the volatile gases unite with the oxygen, and disappear through the channels prepared for their exit. This, say some of the objectors, is unsound in theory—that practically neither sulphur nor phosphorus, the two substances most injurious to iron, are separated by the process.

In support of these views, a writer in the "Birmingham Journal," to whom we are indebted for some excellent remarks on this process, some of which have been imported into these pages, thus reiterates his objections. Recurring to objections formerly urged against the process in the pages of the same journal, the writer says:—

"Especially important, too, is it, that accurate chemical analysis should be resorted to, to show the composition of this iron, and to prove that the new process will truly purge it of sulphur and phosphorus, as we understand Mr. Bessemer to say it will—elements, the presence of one per cent. of which is fatal to the quality of the iron.

"So far as we are aware, this important information has not been communicated to the public; and so long a time has now elapsed that we despair of receiving it from the quarter it was most naturally expected from. In the hope of contributing to the settlement of a question which has already too long disturbed the public mind, we have imposed upon ourselves a task which we think should have been spared us, and present to our readers such an analysis of Mr. Bessemer's iron as we have been daily hoping to see published by that gentleman himself. The specimen we have experimented upon possesses those physical properties which, from repeated descriptions, the public are sufficiently familiar with. The iron consists of an agglutinated mass of large brilliant crystalline grains, possessed of a very imperfect malle-

ability; flattening under the blow of a hammer; but almost invariably cracking at the edges. It is wholly destitute of a fibrous structure, and only after having been repeatedly heated and drawn out in a smith's forge, exhibits the properties of an inferior wrought iron. On analysis it was found to have the following composition:—

Iron	98·9
Phosphorus	1·08
Sulphur	0·16
Carbon	0·05
Silicon	traces
	100·12

"This composition is so accordant with the physical properties of iron, that, the composition being given, the chemist would have no difficulty in predicating its more marked characteristics. Its crystalline structure and fusibility are very satisfactorily accounted for. In order more exactly to illustrate the nature of the change effected by Mr. Bessemer's treatment, we append an analysis of refined iron produced at a large establishment in the neighbourhood of Birmingham. We are indebted to the courtesy of Dr. Percy for this analysis. In was made in his laboratory by one of his assistants, Mr. Dick; the iron was obtained only a few months ago, and may be regarded as representing the average composition of refined iron as made at the present moment in this neighbourhood:—

Iron	95·14
Carbon (combined)	3·07
Phosphorus	0·734
Silicon	0·63
Sulphur	0·157
Manganese	trace
Residue, insoluble in hydrochloric acid	0·53
	100·261

The residue, insoluble in hydrochloric acid, yielded—

Silica	0·3
Alumina, with a little peroxide of iron	0·14
	0·44

"In contrasting the change effected by Mr. Bessemer's treatment with that of the refinery, the following particulars force themselves strongly upon our notice. Mr. Bessemer's method removes most effectually the carbon and silicon, while in the refinery these are but little diminished. The carbon is eliminated with a perfection which we should scarcely have thought possible, but we are without information as to the sacrifice at which this has been effected; the amount of iron oxidized by the vivid combustion which Mr.

Bessemer induces, we are unable to ascertain. The point which most prominently strikes the chemist in Mr. Bessemer's iron, is the large amount of phosphorus which it contains—an amount utterly fatal, we fear, to the value of Mr. Bessemer's method. His treatment, we suspect, does not sensibly diminish the amount of this element; but this, too, is a point on which we must be dependent on Mr. Bessemer. We have had no opportunity of examining the slag produced in the treatment; but we learn from an eminent chemical authority, that at least one sample of it contains no sensible amount of phosphoric acid. We have previously explained that it is by the puddling process that the phosphorus and sulphur are mainly removed; the chemical examination of the tap-cinder of the puddling furnace disclosing an abundance of phosphoric acid. As yet, so far as we can learn, Mr. Bessemer has done nothing towards the removal of this pernicious element, phosphorus; and in this important respect his process must be regarded as a failure."

We have elsewhere incidentally alluded to the strange oversight committed by the objectors to Mr. Bessemer's process—all allusion to his hammering and squeezing processes are invariably suppressed; consequently certain magical results are expected, to which, as it appears to us, he does not lay claim. On the contrary, his specification distinctly claims the peculiar squeezing and hammering process already described; lateral compression and elongated fibrous expansion being the results sought for. It is true, he only mentions this portion of his improvements incidentally, when he claims for the new process facilities for forming large masses of iron capable of producing bars that could not have been obtained by the old process by means of powerful machinery not yet matured, whereby great labour will be saved and the operation greatly expedited. It is obvious, therefore, that great importance is attached by the patentee to the subsequent operations. Nevertheless, with all our desire to see Mr. Bessemer's process crowned with success, we cannot avoid seeing that it has yet much to overcome. Early in October, Mr. Bessemer sent ingots of his pneumatically refined iron to the Dowlais ironworks, where it was operated upon, the result being a fair-faced iron, equal, apparently, on the outer surface, to any ever rolled. It stood the lever or dead test well; but the sharp blow of the ram, and the sharp squeeze of the eccentric straightener, it could not bear, for which its steely or crystalline structure probably accounts. Practical men observed, that along the surface of the rail a stratum of fibrous iron—evidently the result of elongation through the rolls—presented itself; and this was considered great encouragement for Mr. Bessemer to prosecute his idea to perfection.

In reference to this railway bar, Mr. Bessemer states, that it was rolled direct from a ten-inch square ingot, having passed through the rolls fourteen times. The metal was not previously piled or in any way wrought; but, notwithstanding the extremely difficult section, not the smallest portion of the flange was torn up. To render the fabrication of the same form of rail practicable on the old plan, twice-rolled iron is used to form the flange, and ten shillings per ton extra is being paid for it in consequence.

The process is stated to have been successfully applied to the manufacture

of iron for tin-plating. The best puddle-iron has heretofore failed to produce the requisite toughness, and charcoal-smelted iron has in consequence been used for this purpose at the extra cost of several pounds per ton; but we have examined sheets rolled from ingots prepared by the new process, remarkable for their thinness, and affording proofs of the great ductility and toughness of its product.

We have also inspected, as instances of the extreme tenacity capable of being produced by this process, rolled out metal of such extreme thinness and pliability as to bear, when annealed, a close resemblance in fabric to paper, with much greater toughness and tenacity.

We shall conclude these remarks by quoting the concluding portion of Mr. Bessemer's address to the British Association:—"One of the most important facts," he says, "connected with the new system of manufacturing malleable iron is, that all the iron so produced will be of that quality known as charcoal iron; not that any charcoal is used in its manufacture, but because the whole of the processes following the smelting of it are conducted entirely without contact with, or the use of, mineral fuel. The iron resulting therefrom will, in consequence, be perfectly free from those injurious properties which that description of fuel never fails to impart to iron that is brought under its influence. At the same time, this system of manufacturing malleable iron offers extraordinary facility for making large shafts, cranks, and other heavy masses; it will be obvious that any weight of metal that can be founded in ordinary cast-iron by the means at present at our disposal may also be founded in molten malleable-iron, and be wrought into the forms and shapes required, provided that we increase the size and power of our machinery to the extent necessary to deal with such large masses of metal. A few minutes' reflection will show the great anomaly presented by the scale on which the consecutive processes of iron-making are at present carried on. The little furnaces originally used for smelting ore, have from time to time increased in size, until they have assumed colossal proportions, and are made to operate on 200 or 300 tons of materials at a time, giving out ten tons of fluid metal at a single run. The manufacturer has thus gone on increasing the size of his smelting furnaces, and adapting to their use the blast apparatus of the requisite proportions, and has, by this means, lessened the cost of production in every way; his large furnaces require a great deal less labour to produce a given weight of iron, than would have been required to produce it with a dozen furnaces; and in like manner he diminishes his cost of fuel, blast, and repairs, while he insures a uniformity in the result that never could have been arrived at by the use of a multiplicity of small furnaces. While the manufacturer has shown himself fully alive to these advantages, he has still been under the necessity of leaving the succeeding operations to be carried out on a scale wholly at variance with the principles he has found so advantageous in the smelting department. It is true that hitherto no better method was known than the puddling process, in which from 400 to 500 weight of iron is all that can be operated upon at a time, and even this small quantity is divided into homœopathic doses of some 70 lbs. or

80 lbs., each of which is moulded and fashioned by human labour, carefully watched and tended in the furnace, and removed therefrom one at a time, to be carefully manipulated and squeezed into form. When we consider the vast extent of the manufacture, and the gigantic scale on which the early stages of the progress are conducted, it is astonishing that no effort should have been made to raise the after processes somewhat nearer to a level commensurate with the preceding ones, and thus rescue the trade from the trammels which have so long surrounded it."

CHAPTER XV.

METALS WHICH ALLOY WITH IRON.

Iron and Manganese.—Iron unites readily with manganese: where the proportion of the latter metal is considerable, it makes iron harder, whiter, and more brittle. Hence, according to Berzelius, iron in alloy with this metal is the best for making steel. The presence of a little iron in manganese gives it magnetic properties, and renders it less oxidizable when exposed to the air. On the other hand, according to M. Rinmann, manganese diminishes the magnetic power of iron, and in the end destroys it. Dr. Thompson says that a due proportion of manganese diminishes the fusibility of iron, and increases its ductility. M. Karsten affirms that manganese is more frequently met combined with iron than any other metal; in small proportions, it hardens iron without diminishing its tenacity. He has found in bar-iron of good quality, 1·85 per cent. of manganese. It is not ascertained at what point it begins to destroy the tenacity of iron; and it is not easy to make experiments in the investigation, on account of the high temperature required to fuse the two metals. M. Berthier says that pig-iron made from ferro-manganese ores, contains up to 0·07 of manganese; that it is extremely brittle, lamellar (in large flakes), white, and very shining. Mr. Mushet has experimented to combine manganese with iron in augmenting proportions, and concludes that the maximum of manganese in a hundred parts of pig-iron is forty. This compound, containing 71·4 of iron and 28·6 of manganese, is unaffected by the magnet. As to the brittleness of the alloy, it depends on its carbon, and the manner in which the carbon has combined with the iron.

Iron may contain large proportions of manganese, as much, indeed, as steel; and steel need not necessarily contain manganese. According to M. Karsten, it is the carbon in the two which makes the difference between them. Experiments have shown that ferro-manganese ores are the most likely to produce steel, a circumstance which has won them their French name of *mines d'acier*. It is not, however, the immediate effect of the manganese itself, but of the manner in which the carbon combines with this metal, and which is determined by the proportion of manganese present. It follows, M. Karsten remarks, that the white iron, which contains no manganese, ought to become steel as readily as that obtained from ferro-manganese ores, since the latter offer us the iron combined with carbon in the same manner. Fact proves to be in accordance with this theory; but this kind of pig-iron is generally more impregnated with foreign bodies than the iron obtained from ores containing manganese.

M. Berthier found traces of manganese in the white lamellar iron of Musen, in Rhenish Prussia. This iron contained, according to his analysis,

Manganese	0·046 to 0·032
Carbon	0·040
Silicium	0·003
	0·089

According to M. Berthier, the alloy composed of

Iron	0·745
Manganese	0·255

is whiter than iron, shining, very brittle, and with a fine grain. The alloys of the two metals are all the more difficult to fuse, as they happen to contain more manganese; they are more oxidizable than iron; they give out a smell of hydrogen when breathed upon, and readily free themselves from a crust of black oxide when exposed to a moist atmosphere. Warmed under the breath and in contact with siliceous scoria, the manganese oxidizes more readily than iron, and dissolves in the slag; and ultimately all that remains will be pure iron. It is in this way that the refining of manganese irons is effected.

We give the results of some other analyses made by M. Berthier, which denote the presence of manganese in certain crude irons, namely:—

Iron of Lohe, near Musen, obtained from the spathic iron of Stahlberg; white, with large flakes, easily pulverized. A natural steel is made from it, which enjoys a very high reputation.

Carbon . .	0·035
Silicium . .	0·005
Manganese .	0·052

Iron of Ham (Comté de Lamarck), which produces an excellent natural steel.

Carbon.	Silicium.	Manganese.
0·044	0·013	0·074
0·051	0·006	0·045
0 029	—	0·018
0·124	0·019	0·137

Iron of Riou Perou, near Vizille (department de l'Isere), produced by fusing spathic iron with anthracite; white, and very lamellar. Carbon was not experimented for. It is said that this is the only known instance in which a white iron has been produced out of a combustible mineral.

Silicium . .	0.002
Manganese .	0·040
	0·042

According to M. Karsten, the best mode of obtaining the manganese held in combination with iron, is as follows:—Dissolve the iron at 100° in aqua regia, and then decompose (at a very low temperature) the solution, taking care to have it very strongly acidulated by adding successively small doses of carbonate of ammonia dissolved in water. If the iron has been oxidized to its maximum point, and the liquor has been largely mixed with water, and powerfully acidulated, it will contain all the manganese.

M. Quesneville has proposed to separate the two metals by precipitating

their solution with arseniate of potash, after it has been made as neutral as possible, and the iron has been submitted to the maximum of oxidation. The iron separates in the condition of an arseniate, and the manganese remains in solution.

Iron and Mercury.—Iron unites with mercury only under very rare circumstances; and M. Berthier even affirms that the two cannot combine. There is no direct action between the two metals, and this is the reason why mercury is kept in iron vessels. The addition of another metal favours the formation of an amalgam of iron. Mr. Aitkin has succeeded in obtaining it by the following process:—He pounds together iron-filings and an amalgam of zinc, adding a solution of iron in hydrochloric acid. By then kneading the mixture and warming it, the iron and mercury combine by degrees, and assume a metallic brightness. Berzelius was accustomed to produce this amalgam by pounding a mixture of iron-filings, alum, and mercury, at first dry and then mixed with a little water.

M. C. Klauer, of Malhausen, has prepared the amalgam of iron by making a highly concentrated solution of sulphate of iron, and shaking in it the amalgam of sodium freshly prepared. In a few instants he has obtained an amalgam which deposits itself at the bottom of the vessel in a shining mass, silvery white; and the solution, on becoming clear, contained flakes of the hydrate of iron. According to M. Klauer, the amalgam of iron is white, with great tenacity, but may easily be broken into fragments. It is magnetic. In the air it decomposes, and the surface becomes covered with rust. The other metals, according to the same authority, give amalgams in the same way by following the same method.

Iron and Molybdene.—According to Messrs. Hielm, Berzelius, and Thompson, iron combines easily with molybdene. Dr. Thompson tells us that, of all metals, molybdene is the one with which iron unites most readily. Supposing equal parts of the two metals, the alloy is fusible with the blowpipe, brittle, of a bluish-gray, and of considerable hardness; the fracture is lamellar, fine, and granulous. This alloy melts with the blowpipe, swelling out in bubbles, but without giving out any sparks. One part of iron with two parts of molybdene, form a combination of a clear gray colour, not fusible with the blowpipe, obeying the magnet, very brittle, and of a fine, granulous texture.

According to M. Berthier, the alloys of these metals—the *molybdures* of iron—are in every respect the analogues of *tungstures* of iron. An alloy containing 0·20 of molybdene is fusible, whiter than iron, extremely hard, brittle, but of great tenacity; the fracture being equal and granulous.

Iron and Nickel.—Nickel, according to M. Bergmann, readily unites with iron in all proportions; producing a soft and tenacious alloy. The other properties of nickel give great weight to this opinion. The rarity of nickel, however, in a pure state did not permit M. Karsten to use it in the many experiments in iron-refining for which science is so much indebted to him. The statement of M. Hassenfratz that iron treated with *kupfernickel* is not solderable, nor to be forged without great difficulty, and that when cold it becomes brittle, is

not to be much relied on, for he does not seem to have used pure nickel in his experiments, and the *kupfernickel* probably contained arsenic and sulphur. According to Lampadius, an alloy of five parts of nickel and two parts of iron is moderately hard, easily malleable, and has the colour of steel. The alloy of these metals occurs native in aërolites, where the iron contains from three to ten per cent. of nickel. The meteoric iron of Baffin's Bay contains three per cent., and that of Siberia, whose discovery we owe to Pallas, about ten per cent. of nickel—a result for which we are indebted to the careful analysis of Mr. Children. The average, however, of the three analyses made by that gentleman gives 8·96 per cent. of nickel. But, according to the experiments of M. Karsten, the sulphur found by M. Laugier in Siberian iron, is in the state of common pyrites; and he infers that this meteoric iron must be a mixture, and not a chemical combination.

It will perhaps be interesting to record the quantities of nickel contained in different masses of meteoric iron, found at different points of the globe. For a long time there was much doubt as to the origin of these masses of native iron; but the remarkable fall which took place at Agram on the 26th of May, 1751, established the existence of these phenomena beyond further question. The analysis of the aërolites revealed the presence of nickel, which has ever since been regarded as one of their distinctive characteristics. But the progress of chemistry, and a more minute analysis, have led to the discovery of their containing other metals besides nickel; and the investigations of M. Vauquelin have even gone a step further, and shown that some meteoric stones which indisputably fell at Chassigny, near Langres, did not contain any trace of nickel.

M. Proust was the first to establish the existence of nickel in the native iron of Tacumana in America. A few years later, M. Klaproth showed that nickel was present in all the native iron that he had then examined, and which appeared to him evidently of meteoric origin. He found in native iron from—

Siberia .	96·75 of iron	and	3·25	of nickel.
America .	97·50	,,	2·5	,,
Hungary .	96·5	,,	3·5	,,
Bohemia .	98·5	,,	1·5	,,

A little later, Messrs. Boussingault and Mariano de Rivero examined different masses of meteoric iron which had been found on the Eastern Cordilleras. A mass, measuring 102 cubic decimetres, or about 3½ cubic feet, was found in 1810 upon the hill of Tocavita; its weight could not have been far short of eighteen hundredweight. The iron of which this mass consisted was cellular, malleable, and of a granular structure; it could be easily filed; it had a silver-white lustre, with a specific gravity of 7·3. At the time that this mass was discovered, a great many smaller fragments were found on other points of the same hill. Messrs. Boussingault and de Rivero collected two of them; one, weighing 681 grammes, or about 22 oz., consisted of a malleable iron that resisted filing. It had a white, silvery lustre, with as fine a grain as

steel; it forged tolerably well, but was brittle when heated; its specific gravity was 7·6. Another fragment, weighing 561 grammes, or about 18 oz., consisted of iron, cellular in structure, difficult to be filed, but malleable; of a silvery lustre, with a texture similar to that of drawn cast-steel. Some other stones were found near a village called Rusgata. A mass weighing about one hundred-weight, which these gentlemen examined, presented no cavities—its texture was crystalline; although resisting the file, it was malleable, and had a silvery lustre, with a specific gravity of 7·6. Another mass, weighing about fifty-nine pounds, found in the same place, was almost spherical in form, showed a great number of cavities, was very malleable, and the fractures had a silvery lustre.

Messrs. Boussingault and de Rivero, having made the analysis of these masses and fragments, have given the following as the results:—

Mass of 18 cwt. . . .	91·41 of iron	8·59 of nickel.
Fragment of 22 ounces .	91 23 „	8·21 „ plus residue of 0·28
Fragment of 18 „ . .	91·76 „	6·36 of nickel.
Mass of 109 lbs. . . .	90·76 „	7·87 „
Mass of 59 lbs.	7 to 8 per cent of nickel.	

The following is the procedure employed by these gentlemen:—The fragment for analysis was immersed in nitric acid, and dissolved rapidly, leaving but a very trifling residue. To oxidize the iron to the proper point, the solution was then evaporated almost to dryness; water was then added, and the whole precipitated by ammonia. The oxide was separated by filtration, and then washed with hot water. The ammoniacal liquid presented a distinct azure-green colour. Ferrocyanide of potassium produced a white precipitate of a slightly green cast; a circumstance which proved that the colour arose from the presence of nickel, and not from that of copper. To this ammoniacal solution, reduced by evaporation to half its quantity, caustic potash was added; and to make sure of the entire decomposition of the double salt of ammonia and nickel, the whole of the liquid was evaporated, water was added to the residue, and there remained the oxide of nickel.

To collect the nickel which may have remained with the oxide of iron precipitated from the nitric solution, the oxide was dissolved, while moist, in acetic acid. The residue having been dried, was, with proper precaution, treated with water; then, after passing the liquor through a filter, carbonate of potash was added, which produced a slight white precipitate; and on boiling this solution, the precipitate ignited gave the oxide of nickel.

The following is the process followed by Mr. Children, in the analyses which he made of the meteoric iron of Siberia:—He first dissolved it in aqua regia, then precipitated the oxide of iron with pure ammonia; washed, and ignited the precipitate. The ammoniacal solution was evaporated to dryness, the ammonia driven off by heat, the oxide of nickel again dissolved in nitric acid, and precipitated by pure potash, after the mixture had been submitted to ebullition during some seconds. The precipitates were heated to redness. M. Karsten recommends, in testing for nickel, the use of suc-

cinate of ammonia, which he finds better than ammonia; but it is essential, he says, that the iron should be entirely converted into peroxide, and that the solution should be completely neutralized by caustic ammonia before precipitating the oxide of iron by the succinate. It is also essential that the solution should be largely diluted with water.

Mr. C. A. Sheppard has analyzed the aërolites of Louisiana, and finds their composition to be:—

Iron	90·020
Nickel	9·674
Loss	0·306
	100·000

A meteorolite which fell near Kostriz in Russia, on the 13th of October, 1819, contained, according to the analysis made by M. Stromeyer, 17·49 per cent. of iron, and 1·36 of nickel, in a state of alloy. M. Mornay also found in 1811, near Bahia in the Brazils, a mass of meteoric iron which had been first observed in 1784, and which was about seven feet long, four feet high, and two feet thick, the total size being about twenty-eight cubic feet. Mr. Wollaston, who analyzed a fragment of the mass, found four per cent. of nickel.

A fragment of the aërolite found by Captain Barrow in the South of Africa, about 200 miles from the Cape of Good Hope, fell into the hands of Mr. Sowerby, who in 1820 converted it into a sword-blade about two feet and a half long. The blade acquired, in tempering, a very remarkable degree of elasticity. It is now the property of the Emperors of Russia. An analysis made by Mr. Tennant, represents the aërolite to have contained ten per cent. of nickel. M. Stromeyer has often found in the analyses of aërolites, notable proportions of nickel, which could not be detected by the less delicate methods previously employed.

The Esquimaux whom Captain Ross encountered in his expedition to the North Pole, used knives coarsely made out of aërolites found in Greenland. Mr. Wollaston confirmed this fact by an analysis, from which it resulted that the iron contained the customary proportion of nickel. Aërolitic iron is ordinarily very soft. It shares this quality with all iron deficient in carbon. There are some specimens, however, in which this is not the case; and then, if we are to believe M. Karsten, the iron owes its hardness to some other substances besides carbon, and which are often only found in a state of mixture. When the Siberian meteoric iron is heated to faint redness, crystalline figures appear at the surface; and when the polished surface is heated till it becomes blue, yellow markings appear, which, according to Berzelius, are remarkably beautiful. These compounds may be produced artificially. They are ductile; but when the nickel amounts to more than one-tenth, they are less ductile. They do not rust so easily as iron. Professors Faraday and Stodart have succeeded perfectly in obtaining these compounds artificially. To some specimens of good iron, they added three per cent. of nickel; the mixture was then put in a crucible, and exposed to a high tem-

perature during several hours. The metals were melted; and on examining the button, the nickel was found combined with the iron. The alloy appeared to be as malleable and easily worked as pure iron; its colour was tolerably white when polished;—the specific gravity was 7·804. They were equally successful in preparing an alloy corresponding to the Siberian meteoric iron. They melted horse-shoe nails with ten per cent. of nickel: the metals were found perfectly combined, but the alloy was less malleable and was easily broken under the hammer. Polished, it had a yellow tinge; its specific gravity was 7·849. This alloy was affected very slightly by humidity, compared to what would have happened had the iron been pure.

According to M. Berthier, the alloy consisting of—

Iron	0·917	12 at.
Nickel	0·083	1 „

which is obtained by reducing a mixture of the two oxides in a crucible lined with charcoal, is semi-ductile, very tenacious, and has a granular fracture, slightly lamellar. This alloy is identical with meteoric iron.

Iron and Gold.—Iron readily unites with gold by fusion, in all proportions, and in all its states, as malleable iron, cast-iron, and steel. The affinity between the two metals is very great, and their alloy is difficult to decompose. The gold facilitates the fusion of iron—a fact which sufficiently indicates the tendency of the two metals to combine. M. Gellert concludes from this circumstance that gold is much better than copper for soldering works in iron and steel, where delicate workmanship is required. He has likewise assigned to iron the first place among metals in the order of affinities for gold. We cannot stir gold in a state of fusion with an iron rod, on account of the iron dissolving in small quantity. According to M. Karsten and others, iron does not, to any remarkable extent, weaken the tenacity of gold; and, on the other hand, it does not appear that gold produces any bad effect on the iron.

Messrs. Macquer and Leonhardi mention the following alloys as the result of experiments made by the Count de Sickingen:—Three parts of iron and one part of gold enter into fusion together at a temperature inferior to that necessary for melting iron. Equal parts of the two metals gave, by fusion, a grayish mass, somewhat brittle, and attracted by the magnet. With six parts of gold and one of iron, a white alloy is obtained, which is attracted by the magnet, ductile while cold, and at a moderate heat becomes yellow, red, and blue. Nine parts of iron and one of gold form an alloy which resists the file, unless previously subjected to a red heat. With twenty-eight parts of iron and eight of gold, the alloy is as white as pure silver, and more yielding under the file and hammer than ductile iron.

According to M. Hatchett, the alloy formed with eleven parts of gold and one of iron is very ductile, of great resisting power, and harder than gold. Without any preparation it can readily be cut into blocks, laminated, or struck into medals. This alloy is of a pale yellowish-gray colour, approaching to a dirty white. Its specific gravity is 16·885. There is an expansion

of volume after the union of the two metals. Supposing it to have been 1000 beforehand, it is 1014·7 afterwards.

We learn from M. Dumas that the alloy which contains a twelfth of iron is of a pale yellowish colour; that containing from a fifth to a sixth is yellow-gray, and is employed in jewellery under the name of gray gold; while the alloy of three or four parts of iron for one of gold is grayish-white and very hard.

These alloys may be tempered, take a very high polish, and will make very excellent cutting instruments; nearly equal, indeed, it is said, to steel, when the iron is in tolerably large proportions. Dr. Lewis has succeeded in making excellent razors with them. The alloys in which gold predominates serve to make gold of different colours, and are employed by jewellers for this purpose.

For gilding iron, several processes are employed. After polishing the surface, it is covered with a leaf of gold, or it may have a coating of varnish, which is burnt in after having laid on the leaf of gold; or we may precipitate upon the iron the gold dissolved in aqua regia, and in this case the solution must be diluted with sulphuric ether; or, finally, we may rub the metal with an amalgam of gold, and drive off the mercury by sublimation. This is called fire-gilding, and requires the surface of the iron to be covered in the first place with a slight follicle of copper, laid on by the aid of a solution which is made as follows:—

2 oz. of concentrated sulphuric acid, or 3 oz. if the acid be less strong.
$\frac{3}{4}$,, of alum.
$\frac{1}{4}$,, of sal ammoniac.
$\frac{3}{8}$,, of sulphate of copper.
$\frac{1}{2}$,, of sulphate of zinc.
5 ,, of pure vinegar.

The whole dissolved at a moderate temperature in three pounds two ounces of rain or river water.

The iron is rubbed with this liquor and with mercury until a pale coating presents itself, with small drops of the liquid metal on the surface. Then, and not till then, it is treated with the amalgam. The mercury may be sublimed at a temperature corresponding to that which produces the violet colour in the annealing process.

An easy and successful mode is to apply leaves of gold to iron covered with a slight coating of precipitated copper. There is also another kind of gilding which is effected by incrustation, *or haché*. It is unnecessary to state that electro-gilding has superseded most of these processes.

We sometimes meet in commerce with gold alloyed or mixed with iron, or gilt articles which have been worn out in domestic or other uses. In order to remove the gold from the surface with as little mixture as possible of iron, it is rubbed with a file, or, still better, subjected to the action of substances which dissolve the gold, or detach it by acting upon the iron. Thus, for example, M. Berthier recommends smearing the surface with sal-ammoniac moistened with nitric acid, and then heating nearly to dryness; or, still better,

to rub it with oil, and then sprinkle it with a mixture of two parts of sal-ammoniac and one part of nitre, and then heat it. After either of these operations the gold detaches itself by collision, or by simply rubbing with a scratch-brush.

The different mixtures of gold and iron may be assayed by melting them with litharge or with nitre, and adding lead, after fusion, in order to collect all the particles of metal; or, better still, by submitting them to scorification with about sixteen parts of lead and a small proportion of borax. To separate gold from iron, ancient metallurgists prescribed various methods. Some melted the alloy with sulphur and three parts of potash; they then washed in water, which dissolved the sulphide of gold, precipitated the sulphide with an acid, and separated the gold from it by the means we have already indicated. Others melted with one part of copper and two of sulphur; then either roasted the sulphide or treated it with nitric acid, and melted the oxidized substance with litharge and black flux. Copper, from its affinity to gold, is in truth one of the most active agents that can be employed to separate this metal from its combination by the *dry* method. Some employed the contrary method, dissolving it by aqua regia, and precipitating the gold with the protosulphate of iron.

We may also separate gold from iron by means of sulphide of antimony. This is not a good procedure for assays, but it is used by goldsmiths to bring the gold to a high standard, as it removes the minutest traces of other metals, even of silver, which it often retains after cupellation. The operation is thus performed :—The gold is heated in a crucible; and when melted, pure sulphide of antimony is thrown upon it in the proportion of from two to four parts, according to the greater or less abundance of foreign metals. The heat must be applied gently to prevent bubbling over, and care taken that no cinders fall into the mass in fusion, lest it cause it—as is likely—to boil over. To avoid the risk of this accident, the crucible should be of a size which would leave one-third free, even when the mixture of gold and sulphide of antimony is in full fusion. All foreign metals, even silver, pass into the state of sulphide; and the antimony, which the sulphur has abandoned, remains alloyed with the gold. The mixture, when melted, is poured into a conical iron ingot-mould, the sulphide of antimony separated from the gold, which is again melted with a new dose of sulphide of antimony; and this takes place as often as may be deemed necessary for its purification. When the proportion of iron combined or mixed with gold is considerable, it is usual to add sulphur to the sulphide of antimony in the first treatment.

Iron and Platinum.—Iron combines with platinum in all proportions. This combination occurs native, platinum being ordinarily found alloyed with iron. This alloy is easily made in an ordinary furnace, and we should therefore be cautious in putting iron in contact with vessels of platinum at a high temperature. Dr. Lewis, however, could not succeed in the attempts he made to unite these metals by fusion—a fact which probably arose from his using ductile iron; but he was more fortunate when he melted together native platinum and pig-iron. The alloy was excessively hard, but possessed, never-

theless, some ductility when the iron formed about three quarters of it. Its specific gravity considerably exceeded the mean density of the two metals, the platinum having destroyed in the iron its property of expanding as it became solid. This alloy, at the end of ten years, was very little tarnished. At a red-heat it became brittle, and its fracture was black, without any metallic lustre.

According to the experiments of Messrs. Faraday and Stodart, equal parts of these two metals give a crystalline alloy, susceptible of a fine polish, and with a density of 9·862; it does not tarnish in the air, and would be suitable for mirrors. This alloy is tolerably fusible.

Platinum and iron may be joined by soldering them. Messrs. Faraday and Stodart united by this method threads of the two metals, and obtained from them a handsome specimen of damaskeening, by treating them as for damaskeened steel.

M. Berthier, who heated in a crucible lined with charcoal, to 150°,

Platinum . .	0·248	1 at. . .	0·476	1 at.
Iron	0·752	10 „ . .	0·524	4 „

found the two mixtures fused without difficulty. The first button weighed 1·013: the carbon absorbed, therefore, was 0·013. The second button weighed but 1·003, and had therefore absorbed but 0·003 of carbon. The two alloys became completely flattened under the hammer before breaking; their fracture was gray, granular, and a little interwoven. They were easily filed, took a fine polish, and their colour was rather that of platinum than of iron. The alloy consisting of one atom of each metal did not melt readily at a temperature of 150°.

Platinum combined with iron is more readily acted upon by acids, and may be dissolved by nitric acid. To make an analysis of a binary alloy of these metals, it should be treated with aqua regia. The metals are then precipitated with zinc, the precipitate digested with nitric acid, when the platinum will remain.

Iron and Lead.—Chemists are not agreed as to the combination of these metals: some doubt the fact, others admit it under some circumstances only, and some regard it as impossible. Among others, M. Berthier is of the last opinion. Messrs. Macquer and Leonhardi say that iron is, of all metals, the only one that has never been alloyed with lead. M. Gellert remarks that this property of iron renders it very fit for separating lead from other metals, in cases where they have less affinity for the lead than for the iron. It is, at all events, certain that the lead may itself serve as an intermediate means of separating iron from other metals—from silver, for example; for in melting a sufficient quantity of lead with an alloy of iron and silver, the lead seizes eagerly on the silver, and isolates the iron, which is seen to swim on the surface of the lead and silver.

M. Muschenbroeck asserts that he has been able to combine by fusion 400 parts of iron with 134 of lead, and thus to have formed a hard alloy whose tenacity was not the half of that of pure iron. He asserts also that

the specific gravity of an alloy consisting of ten parts of iron and one of lead is only 4·250.

According to M. Rinmann lead will combine with a small quantity of iron, and acquires much greater hardness; but he was unable to form either this combination, or the inverse one, by means of a simple fusion. He only succeeded in effecting a more intimate action of the molecules, either by using iron for the reduction of the lead, or by mixing the oxides and reducing them with powdered charcoal.

Dr. Ure affirms that iron does not unite with lead so long as both these substances preserve the metallic form.

M. Guyton-Morveau, in some experiments made subsequently to those of M. Rinmann, melted a mixture of iron and lead; and records having obtained, on cooling, two distinct layers: the upper one consisting of iron with a little lead; the lower one consisting, on the contrary, of lead containing a little iron. But he does not give the proportions of these two distinct alloys.

M. Thenard limits himself to expressing doubts upon the combination of iron with lead.

Berzelius and Dumas consider the union of these metals as very difficult to be effected; but they appear to admit the results of M. Guyton-Morveau.

M. Hassenfratz has also made experiments with lead, copper, and other metals, placed in small iron cannon, which he then submitted to a white heat. It was a mode of cementing iron in some sort by the fumes of the lead. But however interesting these experiments may be, they lose their value, because of the absence of any statement as to the properties of the alloys obtained; that chemist neither indicating the weight of the lead used, nor the weight of the cannon before and after the operation. Those proportions, nevertheless, were exactly the things which we ought to know; for it is possible that the iron may not be injured except by a large proportion of the foreign metals, in which case the practical worker in iron would have nothing to fear from their influence. When treated after this manner with lead, iron is forged with difficulty, is full of flaws, and brittle when cold.

M. Karsten observes that in M. Hassenfratz's experiments the metals were forced, as it were, to mix in proportions different from those they would have chosen had they been left in the liquid state to the action of their molecules. He has supplied the deficiencies of M. Hassenfratz. The researches he made are interesting in their relation to the metallurgy of iron. Iron ores, it must be recollected, frequently contain lead; and it becomes, therefore, important to understand well the properties of the alloy of these two metals. Treated in blast-furnaces, these substances give lead in a reduced state, which, after the melting, leaves the crucible with the crude iron. After taking down the furnace, it is found under the hearth, either as metal, or oxidized, or transformed into a very beautiful red oxide of lead; or, finally, in the state of a crystallized silicate.

In his experiments, M. Karsten has never succeeded in combining the two metals by simple fusion. Ductile iron without carbon did not melt; with

the addition of powdered charcoal, he obtained (as with crude iron) only lead and white cast-iron, which contained no trace of lead.

Litharge, reduced with crude iron in excess, gave him the same result, plus a certain quantity of scoria consisting of one or other metals.

In substituting ductile iron for crude iron, M. Karsten obtained an alloy with litharge at a very high temperature. The button was completely melted and surrounded on all sides by lead. The scoria was black, and contained a part of the two metals.

The following are the average results of five different experiments which M. Karsten made with 100 parts of ductile iron and 300 parts of litharge:— The button of lead 239 parts instead of 278·85, consequently 39·55 parts of lead were vitrified; button of iron 22·5: it follows that 77·5 parts of iron in the state of protoxide, combined with 22·8 of oxygen, became vitrified. But 239 parts of lead could not supply more than 17·1 of oxygen at the rate of 7·15 per cent. The remainder, therefore, came from the air contained in the crucible, or from that which was introduced during the operation. It is even possible that the substance of the crucible had yielded a certain quantity of it.

The button of iron had not the properties of ordinary ductile iron; its texture was lamellar; it could be easily forged, but soon displayed slight cracks; it was very brittle, possessed no hardness, dissolved without giving the least residue, in nitric acid, and consequently contained no carbon. Saturated with caustic ammonia, and then treated with the sulphate of potash, the solution gave 2·8 per cent. of sulphate of lead, containing 3·06 of metal; so that this regulus, which bore some resemblance to crude iron, was composed of 97·94 of iron and of 2·06 of lead.

The button of lead obtained by the reduction of litharge was dissolved while hot in nitric acid, and the solution treated with sulphate of potash. After neutralizing the solution, the sulphate of lead was separated; the liquid then neutralized, and treated with the benzoate of soda, showed no trace of iron. It follows, therefore, according to M. Karsten, that by simple fusion, iron and lead cannot combine: that cast-iron or carburetted iron, when they reduce litharge, do not yield an alloy; but that pure iron placed in the same circumstances may retain as much as 2·06 of lead—a circumstance which renders it more brittle and more fusible without hardening it: in short, that lead in either case cannot unite itself to a small quantity of iron; results which are opposed to those of M. Rinmann, and to those of M. Guyton-Morveau. It even seems that lead, obtained by the reduction of the scoria, does not owe its hardness or its brittleness to the presence of iron, as was generally believed. Iron, then, is not deteriorated by the presence of lead in the ores, provided they are smelted in blast-furnaces to make cast-iron, since the lead and crude iron cannot combine together.

In decomposing crude iron obtained from plumbiferous ores, analysis has never evidenced to M. Karsten any trace of lead. Nevertheless, it is possible, he says, that a very feeble dose escapes the operations of the chemist. On the other side, as this alloy does exist, as regards pure iron, we cannot but

applaud the efforts of those metallurgists who have made synthetic experiments in reference to this subject. In the assays M. Karsten made in Silesia, he added to the crude iron in the first experiment, one per cent. of lead, and for the second one per cent. of litharge. The iron thus obtained had no defect; but its analysis presented no trace of lead, and the sulphuretted hydrogen used would have readily discovered it, had any been present. These experiments were repeated a third time with two per cent. of litharge, and furnished the same results.

Iron and Potassium.—According to Berzelius, iron combines with potassium by means of heat, and the alloy melts more easily than pure iron, especially when exposed to the air. Air and water both decompose this alloy. According to M. Karsten, cast-iron, when fused with potash, becomes converted, first into a steel-like iron, and then into pure iron, because the carbon is consumed in the reduction of the alkali; but the iron does not enter into combination with the potassium on account of this metal not being sufficiently fixed. It is for this reason also, says M. Karsten, that no alloy is obtained when iron and potassium are fused with the addition of charcoal; or even when we melt, as M. Serullas has done, a mixture of iron-filings, tartrate of potash, and soot. That gentleman is said to have obtained in this way a compound of iron and potassium, which was both gray and brittle; but M. Karsten remarks, that in this operation the iron was probably changed into crude iron or steel.

M. Karsten considers it proved by the experiments of M. Hassenfratz, that potassium can have no mischievous influence on the quality of iron. A gun-barrel, which had been used to decompose potash, and in which a considerable quantity had in fact been deoxidized, admitted of being forged with ease, and the iron was neither defective in texture nor brittle when cold. M. Karsten further illustrates this by pointing out that if potassium combined with iron, we ought to find it in all cases when the ores are treated with charcoal. Yet they have never given a trace of it on analysis. If chemical means cannot discover it, it must be because it exists in very small quantities in the metal, and this small quantity is insufficient to communicate any defect to the iron. Neither has M. Karsten found any potash or potassium either in the slag of blast-furnaces, or in the crude iron smelted by charcoal; and thence he infers that the potassium is reduced in blast-furnaces, is then sublimed, and escapes either by the *mouth* or from the hearth. We may, indeed, collect the potash deposited with several other volatile substances upon the tymp and the walls of the furnace. These deposits contain not only carbonate, but also chloride and cyanide of potassium. According to the experiments of M. Berthier, the sublimate collected from the tymp contains much potash, even when the blast-furnace is fed by coke. Nevertheless, it is just possible that, under other circumstances, in the fire of a refinery for example, iron may combine with potassium or sodium.

To certify this conjecture, M. Karsten added to crude iron during the refinery operation five or six per cent. of potash and of soda. The iron became less easily welded, and of very much less tenacity, although it contained only

a trace of these alkalies. It was not to be doubted that it was to their influence the bad quality of the metal was to be attributed; but we are all the less surprised at this, as we know of many other bodies which, in very small doses, produce analogous effects upon iron.

But these results are of small importance to iron-masters. In practice, we are assured by M. Karsten, it can never happen that iron will be found in contact with alkalies in quantities like these. M. Karsten expresses the opinion that 0·0005 of potassium hardens iron, and diminishes its capability of being welded.

Iron and Silicium.—According to Berzelius, silicium unites with iron, but only at the instant that it is set at liberty—that is to say, in the nascent state. When once isolated, the silicium no longer combines with the iron, and it acts in the same manner in reference to other metals susceptible of forming alloys with it. Messrs. Berzelius and Stromeyer succeeded in forming a compound of silicium with iron by cementing iron-filings in silex reduced to a fine powder, and mixed with pulverized charcoal. This mixture was composed of 3 parts of iron, 1¼ of silex, and 0·66 of charcoal, and exposed to the utmost heat of the blast-furnace. The iron in this operation enters into alloy with the silicium, as in similar circumstances it unites with carbon. The silicide of iron thus obtained, is of a silver-white colour, and ductile: its specific gravity is 6·7 to 7·3, while that of the iron used was 7·8285. We do not know in what proportion of iron and silicium this union may take place.

This alloy, dissolved in acids, disengages silica as a porous mass of about the dimensions of the dissolved silicide. The alloy must be heated to be dissolved in sulphuric acid. Dissolved while cold in hydrochloric acid, it causes the disengagement of more hydrogen than an equal quantity of iron. To judge by these experiments, silicium will not affect in a very sensible manner the tenacity and hardness of iron, but it diminishes its specific gravity. According to M. Karsten, however, it is easy to see, in operations on a large scale, that silicium is very injurious to the qualities of iron; and that a great part of the iron which is brittle when cold, or *cold-short*, owes its brittleness to small doses of this earthy metal.

The tenacity or strength of iron is, according to this metallurgist, considerably diminished by the presence of 0·37 per cent. of silicium. His experiments have likewise shown that the action of silex on iron is much more injurious than that of phosphorus.

MM. Janoyer and Gauthier have found that the strength of iron, smelted with the hot blast, depends very much upon the amount of carbonate of lime used in the operation. Raw iron smelted with a charge that yielded a slag in which the proportion of lime and alumina to silica was B_7, A_{10}, had little strength, but broke readily, and analysis showed that it contained three per cent. of silicon. The large amount of silicon in raw iron smelted with the hot blast, has been ascribed to the easier reduction of silica at the high temperature thus produced. But by increasing the amount of carbonate of lime in the charge, so as to obtain a slag in which the proportion of bases to silica

was B_8, A_{10}, and using a blast at the highest attainable temperature, the iron produced had much greater strength, and contained only 1·8 per cent. of silicon. When the proportion of the bases and silica in the slag was B_{20}, A_{19}, the iron contained only an unappreciable trace of silicon, and the strength was increased in the proportion of 45 to 65. It would appear, therefore, that the inferior quality of iron smelted with the hot blast cannot be ascribed to the high temperature, but is owing rather to the charge not being suitably proportioned, and that when there is a sufficient amount of lime present, silica is not reduced. When the maximum amount of lime was used, the consumption of fuel was on the average six per cent. greater.

If we may believe M. Berthier, silicium does not injure the quality of crude iron; but, on the contrary, it makes it more eligible for all kinds of castings. The largest quantity of silicium that M. Karsten could find was 3·46 per cent., although one per cent. is in general a considerable proportion. Crude iron smelted with coke is in general more siliceous than that smelted with charcoal. Nearly all the steel made in France contains silicium. The following are the results of the analyses made by M. Boussingault, which tend to prove this fact:—

	Iron.	Carbon.	Silicium.	Manganese & Copper.
Fer de Rive	99·825	traces	0·175	traces
Cement steel	99·325	0·450	0·225	traces
Cast steel	99·442	0·333	0·225	traces
Pure steel	99·375	0·500	0·125	traces

It appears from these results that in the cementation the iron, in combining with the carbon, absorbs at the same time a great quantity of silicium. But the presence of carbon is not essential; for pure iron, when fused in a clay crucible, absorbs enough silicium to make it less refractory. The iron under this circumstance becomes hard, brittle, and steel-like.

Sometimes iron, with a very large amount of silicium, is produced under peculiar circumstances; but it cannot be regarded as cast-iron. Plattner and Karsten examined a pig of iron which was silver-white, brittle, lamellar; its density was 7·17; it became yellow by exposure to the air; and contained 8·87 per cent. of silicium, 0·942 of sulphur, 0·18 of aluminum, 189 of carbon, with traces of copper and arsenic.

M. Boussingault found in malleable iron, when melted in a Hessian crucible, more than 0·54 per cent. of silicium. Having analyzed also some of Clouet's steel, he found it composed of:—

Iron	99·20	
Silicium	0·80	(the silica obtained was 1·60)
Carbon	0·00	
	100·00	

This, then, is a siliceous steel: the name steel cannot be withheld from it, inasmuch as it possesses the characteristic property, namely, that of hardening

when tempered. We may, therefore, assume with M. Boussingault, that silicium is at least as necessary for converting iron into steel as carbon is, since it does not appear that it ever exists without silicium, and we know that it may exist without carbon. But we should not hence conclude that carbon is of no use in steel. It is possible that it may be almost necessary, considered as a means of rendering it more easily worked; a fact which supports this opinion is, that all the steels in actual use are more or less carbonized, and that no use has been made of that of M. Clouet. But an experienced artizan who has had an opportunity of comparing the two kinds of steel can alone decide this point.

Iron and Sodium.—Sodium has the same action on iron as potassium, a subject we have treated in an earlier page.

Iron and Tantalum, or Columbium.—It appears that these two metals can combine. According to Dr. Thompson, if we heat to a high temperature, in a small crucible, a mixture of oxide of tantalum and iron-filings, the oxide becomes reduced to a metallic state, and forms an alloy with iron. This alloy has the appearance of white cast-iron, but is without a crystalline texture. It is sufficiently hard to scratch glass. Nitro-hydrochloric acid readily dissolves the iron, and leaves the tantalum as a gray powder. According to Berzelius, iron may be combined with tantalum, by heating the oxides mixed with charcoal to a very high temperature. According to M. Berthier, this alloy is imperfectly fused, and resembles cast-iron. Hydrochloric acid also decomposes it; the iron is dissolved, and the tantalum separates as a black powder, which probably contains charcoal.

Iron and Tellurium.—The alloy of these metals occurs native: it may also be obtained artificially; for, according to Berzelius, tellurium easily unites with metals, and forms with them compounds analogous to the sulphides; but its alloy with iron has not, as far as we know, been yet examined.

The telluride of iron is very rare: it is found at Facebay, near Salathna, in Transylvania, accompanied by gold, &c., in small veins, in an earth composed of schist and diorite. It is found in fine grains, or in small flattened crystals, which present hexagonal prisms, broad on one side, and terminated by annular facets. It is either coloured like tin or gray steel, and is soft and fragile. Its specific gravity varies from 5·7 to 6·6. M. Klaproth found in it—

Iron	0·0720	1·0000
Tellurium	0·9255	
Gold	0·0025	

It consequently contains more than five atoms of tellurium for one of iron. Mr. Sheppard announces that he has found in Guildford County, in the United States, a piece of telluride of iron weighing more than thirty pounds, and presenting crystals of a regular octahedral form; but no analysis was made.

Iron and Titanium.—Titanium has very little affinity for iron, and the

two metals cannot combine except under artificial conditions. In several experiments made by Messrs. Faraday and Stodart, they endeavoured to reduce the ferric-titanate with pulverized charcoal, or titanic acid mixed with iron and charcoal; but the fixed regulus did not present the least trace of this substance, notwithstanding the extreme heat used by them. In some earlier experiments, Messrs. Vauquelin and Hecht had obtained an infusible mass of a clear gray, sprinkled with yellow metallic specks, which they regarded as a combination of iron and titanium.

However this may be, the alloy is to be found in nature, and the compounds of these two metals constitute a multitude of different minerals, in which the titanium is in the state of titanic acid. The iron is found also in some in the form of protoxide; but it is found also in others in the form of peroxide. The titaniferous ores of iron exist in abundance in old rocks and volcanic rocks. These minerals are of a metallic black, approaching brown, when they contain a great quantity of titanium; their fracture is of a bright conchoidal form; they are magnetic, and nearly always polar when they contain as much as half of their weight of oxide of iron. In this case they are also soluble in aqua regia; but when they contain more than a half of their weight of titanium, they are ordinarily without magnetic power, and unaffected by acids.

Before the blowpipe, titanates of iron are infusible by themselves; they dissolve in microcosmic salt. In the reducing flame, the glass is nearly colourless when hot; but on cooling, becomes of a more or less deep red. When tin is introduced, the colour due to the oxide of iron disappears, and there is no other reaction than that of the titanium. In this case, if the metal be in considerable quantity, the glass is of a pure blue violet; if in very small quantity, the glass is colourless.

M. Berthier, from whom we borrow these details, adds that the result of the principal analyses of titanates of iron, lead him to the opinion that the protoxide of iron and titanic acid are found combined in various proportions in nature, and form, in consequence, several distinct mineral species. Titanium is frequently found in the north, and especially in Norway. It makes iron ores so hard to work, that in the furnaces at Arendal, which are worked by charcoal, and are nearly forty feet high, it has been found sometimes impossible to smelt them; and those containing it in large quantities are thrown aside. Far from injuring, indeed, the quality of the products, it increases both their tenacity and hardness.

M. Hassenfratz made an experiment in which he replaced titanium with rutile, which, according to M. Klaproth, is its oxide. He found that the iron treated by this substance could be easily forged, without being either defective in texture or brittle when cold. Titanium requires for reduction and fusion a much higher temperature than is necessary for iron. It is for this reason, says M. Karsten, that the oxide of titanium remains almost entirely in the slag, and more especially since the affinity between the two metals appears to be very feeble.

In blast-furnaces, small cubic crystals of a beautiful copper colour are often

found. Dr. Walchner of Fribourg, in Brisgau, has often observed them in the smelting-furnaces of Baden, particularly at Kandern. M. Zinken has made analogous observations while examining the scoria of a blast-furnace at Magdesprung. These crystals have since been found by Wöhler to be not, as was supposed, metallic titanium, but a compound of cyanide and nitride of titanium, containing eighteen per cent. of nitrogen and four per cent. of carbon. M. Karsten has also found the same class of crystals in the scoria of several forges in Germany. He mentions, also, that M. Grigon had already remarked them in 1757, but they were then taken to be iron pyrites. M. Karsten has also observed, at times, little globules of titanium in gray pig iron, a proof of its small affinity for iron. He says, that in the refinery operations, titanium is, in a great measure, separated from iron; nevertheless, traces are sometimes found in ductile iron.

Although titanium is not soluble alone in acid, it dissolves when combined with iron. It ought, therefore, to be looked for in the fluid when making an analysis.

Iron and Tungsten.—Iron combines with tungsten. The Messrs. D'Elhuyart have obtained this alloy by heating to the proper point, in a crucible, a mixture of 100 parts of iron, 50 parts of the yellow oxide of tungsten, and a sufficient quantity of charcoal. After fusion and cooling, they found a perfect button of a brownish-white colour, hard, rough to the touch, and of an even fracture. It represented 137 parts. M. Hassenfratz, in some analogous experiments, had already obtained an alloy of the two metals, which forged easily enough, although slightly brittle; it was ductile, cracked in the tempering, and assumed in forging partially a fibrous, partially a granular texture. M. Karsten concludes from these experiments, that tungsten (in this respect resembling titanium) only increases the hardness of iron. The alloy composed of

Iron	0·63	6 at.
Tungsten	0·37	1 „

is, according to M. Berthier, of a whiter gray than iron, shining, hard, more brittle than ordinary cast-iron, and of a lamellar structure.

Iron and Zinc.—The possibility of uniting the metals was, and is still, a subject of doubt and dispute among chemists. It is, indeed, easy to understand that two bodies would not readily combine, one of which is somewhat volatile and the other very refractory; yet does this alloy occur in certain iron ores and calamines which nature offers us. According to M. Henkeln, zinc and iron form an alloy, hard, sensible to the magnet, and resembling silver. But he does not indicate the proportion of the two metals, nor the manner in which their combination is effected. Mr. Cramer says, that, to effect this, we must bring the iron to a red heat (with small charcoal) and up to the point of fusion, and then add to it the zinc. But Mr. Crells denies the fact of the combination, because the zinc must, according to him, be volatilized by the high temperature of the iron. M. Rinmann is of the same opinion, and has tried to combine the two metals by the reciprocal reduction of their oxides. But,

according to Professors Macquer and Leonhardi, his experiments have not conducted to any certain results. He obtained, no doubt, a kind of iron softer and shorter, but with no certainty that it contained zinc. Later M. Gmelin made some unsuccessful attempts to alloy the two metals by fusion. Yet, so far back as in 1742, M. Malonin satisfied himself that we can make a sort of tin with zinc—a fact which proves the possibility of a combination between the two metals. When a blade of thin iron plate is plunged into a solution of sal-ammoniac, then into a bath of melted zinc, and withdrawn rapidly, a thin but uniform coating of zinc is found attached. It was considered that this variety of tin was not likely to be applied to any useful purposes; but under the name of galvanized iron it is now produced in large quantities, and has been put successfully to a great variety of purposes.

According to the experiments of M. Hollander, a white, brittle, metallic mass is obtained by heating to a red heat, for some time, a mixture of pounded pig-iron and of zinc in a hermetically closed vessel. Dr. Lewis denies the impossibility of effecting this alloy, which, according to his experiments, is hard, somewhat malleable, and of an almost silvery white.

M. Thenard holds that zinc cannot unite with iron. M. Dumas, on the contrary, admits the combination: but says it cannot be effected but by means of some very nice precautions. If we heat the metals together, the zinc volatilizes at a white heat, and pure iron remains; but at a moderate temperature the alloy may be effected. According to him, the temperature at which zinc fuses—a dull red-heat—is the best. He adds, that zinc may be easily combined with a small per-centage of iron, by melting it with iron-filings. The zinc of commerce contains ordinarily one or two per cent. of iron.

According to M. Berthier, who has made many very interesting experiments on the alloys of zinc, the affinity of this metal for iron is very weak, and it is extremely difficult to form the alloy directly. When iron-wire is cut up in small pieces, well mixed with granulated zinc in excess, and heated with black flux, there is but a very small quantity of alloy deposited at the bottom of the crucible; most of the zinc volatilizes, even when the operation is conducted very slowly, and the heat carefully regulated; and the iron-wire preserves throughout its polish and lustre. But the alloy which is so difficult to prepare in our laboratories, is to be found but too frequently in the furnaces where zinc is smelted. When it is melted in cast-iron pans to separate the oxides and impurities with which it is mechanically mixed when it issues from the distilling tubes, it gradually corrodes them; and some time after there is found at the bottom of the pans an alloy which cannot be used in the arts, and which must be distilled in order to extract the zinc in a pure state. This alloy is formed of concentric mammiform layers, with a shining crystalline texture. It is very brittle, very hard, and less fusible than pure zinc; it dissolves easily in weak nitric acid, and leaves a micaceous metalloid residue, which proves it to be black-lead—arising, no doubt, from the portion of cast-iron dissolved by the zinc. Two ferric alloys, one from the great works at Liege, belonging to Messrs. Mosselman, the other from the works near Gisors, were analysed by M. Berthier:—

	Liege.	Gisors.
Iron	0·0500	0·0400
Black-lead	0·0024	0·0020
	0·0524	0·0420

These alloys remain attached to the bottom of the pans, and do not dissolve in the remains of the zinc; but as he has never found any alloy containing more than 0·05 of iron, although the corrosion of the pans continues indefinitely, it is obvious that when the alloy has arrived at a certain degree of saturation, it transmits a portion of the iron which it contains, to the upper layers of zinc, by cementation, and that the portion it thus abandons is again replaced from the sides of the pans.

By gradually heating the ferruginous alloy produced in the zinc works, together with black flux in covered crucibles, any amount of zinc may be separated by volatilization, and any required alloy of iron and zinc obtained. But a powerful white heat completely separates the two metals, without the zinc vapours carrying with them any of the iron, or the iron retaining the smallest trace of zinc. The pig-iron which is produced from calaminiferous ores has never presented, according to M. Berthier, the least trace of zinc.

M. Karsten has specially directed his attention to the action which iron and zinc reciprocally exercise on each other. According to this learned metallurgist, it is not to be doubted that zinc combines with a small quantity of iron; we scarcely can find any, he says, which is entirely free of this latter metal, even when taken from calamine treated in a distilling apparatus. The presence of the iron renders it harder and more brittle. Zinc melted in a furnace at a high temperature and slowly cooled, absorbs sometimes from two to three per cent. of iron (a proportion, it should be remarked, which does not agree to M. Berthier's maximum of 0·05 of iron), which renders it so hard that it may be pulverized. Pure iron cannot, according to M. Karsten, reduce the oxides of zinc, and by using pig-iron the iron is partly refined. The reduced zinc escapes in vapours, and the principal portion of its oxide unites with that of iron, forming bluish-black scoriæ.

To form an accurate opinion of the influence of zinc on iron, M. Karsten made some experiments on a large scale at a forge in Konigshütte (Silesia), in a blast-furnace fed with coke. He smelted thirty-two hundredweight of calamine, containing 16 per cent. of zinc and 31 per cent. of iron, and which, consequently, were too poor to be treated for zinc. M. Karsten did not add to this iron ore any flux or charge. The vapour from the furnace issued in torrents; a bluish-green flame rose from twelve to fifteen feet above the opening; the mouth of the tuyere was constantly covered by a crust of indurated substance; but by diminishing the charge, the heat was raised to such a degree that the slags (of a deep blue colour) acquired a stone-like fracture.

The iron issued from the crucible impetuously, and at first presented the appearance of the best gray pig-iron; but it was very red, and cooled so rapidly that it flowed with difficulty into the pig-bed. On cooling, the upper surface was found covered by a tolerably thick crust indicating considerable

oxidation. Its fracture was granular, brilliant, and like that of gray pig-iron. Taken as a whole, it was soft, capable of bearing the hammer, without being, however, very tenacious. It might easily be divided into small fragments, a proof of the small tenacity existing in the granular structure. In running, it gave out neither flame nor odour.

The general working of the furnace was in no way deranged at first by the presence of the zinc; but two days after the experiments had been concluded, a large quantity of vapour was seen escaping from the mouth and from the anterior crucible; and the flame, particularly at the tymp, presented the brilliancy of that of zinc in the act of combustion. Very soon, and without any change in the charge, the furnace became, to a great extent, cooled; the iron white and rough, the slags black and porous, and the mouth of the tuyere was covered with indurated substances. This lasted five days, and endangered the safety of the furnace.

The iron obtained in these experiments was refined in the forges at Kreutzbourg. It fused and preserved all its characters. Red and remarkably liquid scoria formed in large quantities; the flame which rose from the mass was white, brilliant, and occasionally of a bluish or yellowish colour. After fusion had been effected, pains were taken to allow the scoria to congeal over the liquid metal. Small jets of bluish-yellow flame were then seen to traverse the surface with a slight murmuring noise. The conversion of the crude iron into malleable iron was so rapid, that the mass could only be turned once. A very small quantity of soft scoria was found, and the iron contained in the crucible was so dry that it was necessary to throw into it a large mass of slag, a circumstance quite different to the manner in which coke-smelted cast-iron is found to act in the refinery.

The refining operation perfectly succeeded. The iron was soft; it might have been cut with a hammer if the iron had not been at the same time of extreme tenacity; and finally, it was neither hot-short nor brittle when cold. A very small trace of zinc was found at the bottom; but the ductile iron contained none.

The preceding observations suffice to dissipate all apprehensions about any injury arising from the presence of zinc in ores. But that there might be no doubt left, M. Karsten made some refinery experiments by adding to native iron a certain quantity of zinc, either in the metallic state or as an oxide. The iron thus obtained was of an excellent quality, but on analysis no trace of zinc could be found. M. Rinmann also is of the opinion that zinc ought to excite no apprehensions in ironmasters.

M. Hassenfratz, in his experiments, obtained results somewhat different. The iron was readily forged, but it was somewhat red-short and brittle when cold. However this may be, M. Karsten was not led by his experiments to attribute to zinc any injurious action upon iron. The disturbance of the furnace appeared to him only the effect of the extensive evaporation, and of the cooling which that must necessarily produce.

Iron and Aluminum.—Iron combines with aluminum, and, according to M. Karsten, more intimately than with silicium. Messrs. Faraday and

Stodart obtained an alloy of iron containing 0·064 of aluminum and some carbon, by keeping under fusion during a very considerable time a mixture of highly carburetted steel with alumina. This alloy was white, very brittle, with a granular texture. Alumina seems to be more injurious to the quality of iron than silicium. The experiments made by M. Karsten in reference to the refinery operations in Upper Silesia, showed that the addition of clay produced iron of a more than ordinarily brittle quality.

The mischievous influence attributed by M. Karsten to aluminum does not appear, however, to be corroborated by the experiments of Messrs. Faraday and Stodart, who concluded that aluminum in small quantities does not impair the quality of iron, and that it appears considerably to improve that of steel. This statement induced M. Karsten to repeat his experiments: he added clay to cast iron during the refinery, and repeated his experiment on a larger scale three times. The large quantity of silicate of iron formed on the hearth in consequence of this addition, delayed the operation; but the quality of the product did not appear to be sensibly altered.

The analysis of the iron thus produced showed no trace of aluminum in the metal. The other samples of wrought-iron, steel, or cast-iron analyzed by M. Karsten, presented traces of aluminum so slight as not to admit of being estimated; but the largest amount was always found in iron which was brittle when cold. M. Karsten hence maintains his opinion that aluminum does exercise an injurious influence on the tenacity of iron. Messrs. Stodart and Faraday insist, on the other hand, that steel and forged iron do not act in the same manner in their combinations with other metals. This must be admitted to be true; and it may happen that a small proportion of aluminum, which may be too trifling to affect the quality of steel, may deteriorate that of iron.

The forges of Alt-inter-l'Ind, near Fichtelberg in Bavaria, are accustomed to refine the cast-iron made in the blast-furnace of Konigshütte, near Arzberg, on the frontiers of Bohemia. This iron is partially gray and partially speckle-coloured. It is obtained by treating a mixture of micaceous oligistic iron and brown hematite. In smelting these ores, clay is used as a flux; which fact, according to M. Huber, renders it probable that the cast-iron of Konigshütte contains both aluminum and silicium, a conjunction which he thinks aids the refinery operation. This cast-iron has always yielded ductile iron, peculiarly fit for the fabrication of sheet-iron.

But it remains to be seen if a careful analysis of the iron would reveal more aluminum than M. Karsten found in the specimens examined by him. Dr. Schafhäutel and M. Bohm of Munich, have introduced clay into a composition which they propose for the purpose of improving and softening cast-iron in the refinery operation. In a patent which the former gentleman took out in London (May 18, 1835) for his method, he describes it as follows:—To produce malleable iron, we take 1¾ lb. (857 grammes) of black oxide of manganese, 3¾ lbs. (1 k. 886) of muriate of soda, and 10 oz. (306 grammes) of potter's clay. These substances should be of a pure quality, perfectly dry, and free from all heterogeneous intermixture; they are reduced

into a fine powder, and well mixed. In a puddling furnace, 300 lbs. of iron in small pigs is treated with the customary quantity of slag. When the mass is in fusion, the register of the chimney is lowered, until the flame, in its passage over the hearth, is both clear and transparent, so that the metal may be seen during the whole of the operation. If the flame takes a dull yellow colour, the orifice in the door of the hearth should be opened in order to increase the draught. Three or four minutes after the mass is in perfect fusion, which will depend on the greater or less draught of the furnace, the metal assumes a pasty consistence; and the mixture above-mentioned, which ought to have been kept hot and dry near the furnace, is then added. It is to be divided into twelve parts, each weighing half a pound, and introduced into the furnace at intervals of a minute or two by means of a small cylindrical shovel, holding about half a pound. As soon as the first portion is thrown upon the metal, it must be incorporated with it as soon as possible by the help of a large poker; the mass then becomes more liquid, and pale yellow flames proceed from its surface: two minutes later the next portion is thrown in, and so on with the rest. After the third or fourth addition, the mass bubbles up in consequence of the disengagement of the gas. As this is the instant when the iron is separated from its impurities, extreme care must be exercised. The surest means of determining the time for the introduction of these substances is by observing if the height of the flame diminishes; for this decrease announces that the effect of the preceding portion is exhausted, and that another should be added. In every case, care must be taken that the mass does not become too consistent, which is prevented by adding more of the powder; but the character which most certainly indicates that the operation is accomplished, is the blue colour of the flame. To obtain hard iron fit for steel, three or four shovelfuls of the splinters and waste iron left by the flattening machines, and three shovelfuls of slag, are used; but in this case only half the manganese before recommended is necessary.

M. Elie de Beaumont saw this process in use in several establishments in Germany. By some it is very highly spoken of; by others the results were said to have been far from satisfactory. It has also been tried in some French forges, but with no decisive result. According to Dr. Thompson, a globule of iron, melted by galvanism in contact with moistened alumina, forms an alloy with aluminum. The alloy effervesces slightly under water, becoming covered with a white powder.

Iron and Antimony.—The union of iron and antimony is readily effected by fusion, and it would seem that it may take place in all proportions. These two metals have a great affinity for each other. Their alloys are much more fusible than iron, and are white, hard, and very brittle. Their specific gravity is less than the mean of that of the two metals. According to Dr. Thompson, this alloy may be obtained by fusing in a crucible two parts of sulphuret of antimony and one of iron. This alloy was formerly called *regulus martialis*. It is still used in medicine for the preparation called "Mars' saffron," the "aperient antimony" of Stahl.

The magnetic character of iron is much more diminished by its alloy with antimony than almost any of the other metals. The iron is also rendered more hard, much more fusible, and brittle like cast-iron. Antimony, in uniting with iron, becomes harder and less fusible. M. Karsten made some experiments on this subject in the Kreutzbourg forges in Upper Silesia. He added to the cast-iron, after its liquefaction, one per cent. of antimony. Notwithstanding its volatility, this metal exercised on iron a worse influence than even tin. The iron became very brittle at all temperatures. These results agree with those of M. Hassenfratz. In analyzing this iron, twenty-three per cent. of antimony was found.

M. Karsten received from another Silesian establishment, specimens of iron very brittle when cold, which quality was attributed to the presence of antimony. By analysis, he did not obtain more than 0·114 of antimony, together with a trace of sulphur, and 0·38 per cent. of phosphorus. The brittleness of the iron, in his opinion, was attributable solely to this small quantity of antimony.

By heating antimony in excess with iron at a high temperature, a fusible alloy is formed, containing, according to M. Dumas, one atom of antimony and one of iron, or seventy parts of antimony and thirty of iron. This alloy is very hard, white, and feebly magnetic. When the quantity of iron is increased, the alloy becomes still harder, presenting also the singular character of giving out sparks when briskly filed. Reaumur, who was the first to discover this remarkable fact, produced his alloy with two parts of iron and one of antimony. According to M. Berthier, the antimonide containing 0·705 of antimony, or one atom of antimony, for one atom of iron, cannot be decomposed by the most intense heat; but the antimonides which contain a larger proportion of antimony, are reduced by a high temperature to one atom of antimony for one atom of iron.

M. Hervé made some experiments in 1827 with regard to the union of iron and antimony, of which the following is an abstract:—To try if antimony possessed the quality of effecting, like tin, the fusion of wrought-iron, he exposed it, with about twenty per cent. of antimony, to a high temperature in a covered crucible. But the iron was not melted, although it certainly would have been melted with the same quantity of tin under the same circumstances. It would seem, however, that a certain portion of the antimony must have united with the iron, for on taking the metal out of the crucible, it gave off white vapours, arising from the volatilization of antimony. The malleability of the iron did not appear to suffer much from this operation. He then made three attempts to alloy, by fusion, cast-iron with antimony in the following proportions:—

100 parts of cast iron		and 1 part of antimony			
100	,,	,,	and 2	,,	,,
100	,,	,,	and 3	,,	,,

The antimony was not added to the iron until after the latter was already in a state of fusion in the crucible. They were melted in separate bars.

1st Bar.—Fracture uneven, striated, lamellar; a confused, divergent crystallization; grayish-white; tolerably bright. Under the file, steel-gray and bright; under the grinding-stone, iron-gray and bright.

2nd Bar.—Fracture uneven, striated, lamellar; a confused, divergent crystallization; grayish-white, but of little lustre. Under the file, grayish-white, and not bright; under the grinding-stone, iron-gray and shining. This bar was very hard and brittle; when allowed to fall on some stone steps, it broke in two, although it measured 17 square millimetres (about six inches).

3rd Bar.—Fracture uneven, lamellar; confused, divergent crystallization; grayish-white. Under the file, grayish-white, brilliant; under the grinding-stone, a little darker than under the file, brilliant. This bar, which had the same dimensions as the preceding one, broke also on falling from a height of three feet on stone steps.

It seems to result from these operations, that antimony is not entirely volatilized when projected into cast-iron in a state of fusion; but that a portion remains combined with the iron in consequence of its affinity for this metal, and also that antimony exercises a very considerable influence on the crystallization of iron during the process of cooling. We see, in fact, that the proportion of one part of antimony to a hundred parts of iron, is sufficient to alter the fracture of cast-iron; and that it remains the same until the antimony reaches five per cent., and then the fracture resembles that of zinc.

Iron and Silver.—There does not seem to be any question that these metals combine; but the observations of chemits with regard to their alloy, are not altogether concordant. M. Berthier and M. Thenard consider that the alloy cannot be produced; but that iron heated with silver retains a certain quantity of this metal. M. Berzelius states that these metals combine readily when melted together, and that they cannot be separated by cupellation with lead, but only by means of acids or by fusion with borax or nitre.

Wallerius states that iron combines with silver by fusion, and that the alloy, consisting of equal parts of iron and silver, has the colour of silver, considerable ductility, greater hardness and less elasticity than silver. This alloy is attracted by the magnet.

Rinmann states that silver may be combined with one-fifth of iron, without losing its tenacity and malleability, but becoming much harder. This alloy is stated to be applicable to the manufacture of buckles, fruit-knives, &c. Macquer and Leonhardi obtained a similar alloy.

Coulomb states that silver cannot retain more than 1-150ths of iron; and Guyton Morveau states that iron cannot retain more than one-eightieth of silver, which is said to communicate to it remarkable hardness, and a very fine texture.

Karsten found that by the addition of fifteen per cent. of fine silver to iron during the refinery operation, the quality of the iron was sensibly deteriorated: it did not forge well, became scaly, the bars presented cracks at the edges, and otherwise resembled hot-short iron. Analyses showed that it contained

0·034 per cent of silver. It would appear, therefore, that silver has the same influence as sulphur upon iron, although in a less marked degree.

Iron and Arsenic.—These metals may be combined by fusion in any proportion. When the amount of arsenic is large, the magnetic character of the iron disappears. The alloy of these metals is more or less white, hard, brittle, and fusible, according to the amount of arsenic. It is crystallizable, its fracture more dense, and the texture closer than that of iron; according to Achard, similar to that of steel.

M. Cadet asserts that this alloy will receive a brilliant polish, and that articles of jewellery are made from it. Berzelius says that 100 parts of iron-filings heated to redness, in a matrass with 200 parts of arsenic, retain 186 of arsenic without melting. M. Thenard says that an alloy formed of 1 part of arsenic and 2 parts of iron, is of a grayish-white colour, without any action on the magnetic needle; very brittle; considerably more fusible than iron; it absorbs oxygen gas from the air by the aid of heat, and becomes converted into volatile oxide of arsenic and fixed oxide of iron.

This alloy is obtained by heating iron-filings with a little more than half its weight of powdered arsenic in a covered crucible. According to M. Berthier, a true arsenide cannot be obtained by simply heating iron with arsenic; the greater part of the arsenic volatilizes before the combination can take place. No better result is obtained with a mixture of arsenious acid and charcoal; but by gradually heating to whiteness 100 parts of powdered smithy scales, 50 of arsenious acid, 50 of carbonate of soda, and 20 of starch, the arsenide is obtained; and when melted a second time with arsenious acid, carbonate of soda, and starch, absorbs 25 of arsenic. Finally, by heating the arsenide a third time with the same mixture, it still absorbs 15 of arsenic; it is then saturated, and it contains a little more than one atom of arsenic to two of iron. This arsenide is slightly vesicular, granular, and easily pulverized.

According to M. Berthier, the arsenide of iron saturated with arsenic is composed of—

Iron	0·59	100
Arsenic	0·41	69·39

It is of an iron-gray colour; very brittle, with a lamellar fracture, presenting large and very shining scales; it is not magnetic, and is very fusible. When roasted it becomes converted into a sub-arseniate of peroxide of iron, and disengages arsenious acid. It is not acted upon by sulphuric or muriatic acids; is easily dissolved by nitric acid, and nitro-hydrochloric acid, which converts it into arsenate of peroxide.

According to the experiments of Bergmann, small quantities of arsenic do not render iron either hot-short or cold-short. Berzelius, however, is not of this opinion: he thinks a very small quantity will make iron brittle when cold. M. Berthier states, also, that a very small quantity of arsenic suffices to affect the malleability of iron, and renders it brittle when cold. According to the experiments of M. Hassenfratz, this alloy may be forged extremely

well, but it cannot be welded: it gave out an odour of garlic while being hammered, and appeared generally rather hot-short than cold-short.

In the experiments of M. Karsten, it was found that a little arsenic, added to iron during the refinery, retards the operation to such a degree, that it occupies two or three times as long to effect it. A great quantity of corrosive scoria, with a strong affinity to the iron, is produced, which occasions a considerable loss; so considerable, indeed, that were the experiments continued with larger proportions of arsenic, they would cause the oxidation of the whole mass.

The iron was considerably harder, presented a steel-like character when forged, was without crack or flaw, and not hot-short, but its strength was diminished. Analysis did not indicate a trace of arsenic. M. Karsten adds, that the iron is dissolved very slowly by acids; a fact which, in his opinion, indicates a change in the quality of the iron.

M. Lampadius observes that at the forges at Breitenhof, in Saxony, a very rich red oxide ore was found to yield iron so hot-short, that it could not be worked; and the pig-iron was found to contain 3·5 per cent. of arsenic. Wöhler found arsenic in four specimens of pig-iron from different furnaces; and Schafhäutel states, that even the best Swedish bar-iron contains arsenic, the Low Moor iron still more. It is said, that in forging English cast-steel the odour of arsenic is frequently recognizable. Opinion is much divided as to the influence of arsenic upon the quality of cast-iron; generally it is said to render it more brittle and fusible.

When Algiers became a French colony, there was found among the materials contained in the arsenals of Casauba a quantity of bombs and cannon-balls that could not be employed as they then stood; they were, therefore, imported into France, to be melted and cast into projectiles of other calibre; but it was soon discovered that nothing could be done with them, the quality of the iron being so bad. M. Berthier was commissioned to examine separately the bombs and balls to ascertain their nature. The iron of the bombs was grayish-white, very brittle, and was easily reduced to a fine powder. Its specific gravity was found to be 7·585. The iron of the balls was still more brittle than that of the bombs; with a little care it was easy to break them across, and then it was observed that they presented a fracture with rays springing from the centre and ending at the circumference. These balls were craggy and pitted at the surface, and nearly always cavernous. The density of one fragment was found to be 7·65.

This cast-iron, according to an analysis by M. Berthier, contained the following proportions of arsenic and carbon:—

	Bombs.	Balls.
Arsenic . . .	0·098 . . .	0·270
Carbon . . .	0·015 . . .	0·010
	0·113	0·280

It contained neither sulphur, manganese, copper, nor silicium.

In Bedford County, Pennsylvania, arsenietted native iron is found composed of

Iron	0·9744	0·9940
Arsenic . . .	0·0156	
Plumbago . .	0·0040	

and containing neither sulphur nor nickel.

This mineral is crystalline and composed of small rhomboidal prisms; its colour is between silver-white and steel-gray. It cannot easily be broken, and may be flattened like wrought-iron; the fracture is craggy; the metal is as hard as steel; its specific gravity is 7·337; it is very magnetic and polar.

The arsenide of iron is found very frequently at Reichenstein, in Silesia, in a serpentine rock, and is worked for the arsenic. The crystals are of the prismatic system. Klaproth discovered in it 0·38 of iron and 0·62 of arsenic; but the results obtained by two other chemists are as follow:—

	M. Karsten.	M. Hoffman.
Iron	0·324	0·281
Arsenic . . .	0·659	0·660
Sulphur . . .	0·017	0·020
Gangue . . .	0·000	0·022
	1·000	0·983

M. Karsten says that it contains magnetic pyrites, which can be separated by means of the magnet. In this case the mineral would consist of 2 atoms of iron and 3 atoms of arsenic; but M. Hoffman concludes from his analysis that the ore of Reichenstein is arsenide $FeAs^2$, mixed with 0·0526 of common pyrites.

Another natural combination of iron and arsenic is "mispickel," or the arsenio-sulphuret of iron. This ore is of a grayish-white colour, metallic, with a granular fracture. Its primitive form is a right rhomboidal prism; its specific gravity 5·6. When heated alone in a closed tube by the blowpipe, it yielded at first a red sulphide of arsenic, then a black sublimate, and finally metallic arsenic. The residue appeared to be magnetic pyrites. Heated on charcoal by the blowpipe-flame it gives off a thick vapour of arsenic, and melts into a globule presenting the appearance of magnetic pyrites. It is not dissolved by muriatic acid. It contains, according to M. Berthier:—

Iron	0·335	1·000
Arsenic . . .	0·465	
Sulphur . . .	0·200	

Its formula is $FeAs^2 + FeS^2$.

Iron and Bismuth.—These two metals appear to combine, but chemists are by no means agreed on this point. Berzelius and Thenard say that bismuth combines with difficulty with iron; and that a small portion of iron

suffices to render bismuth magnetic. Brand, Henkel, and Gellert record having obtained a compound of from two to three parts of bismuth with one part of iron; but Baumé denies that this can be done. Rinmann did not succeed in producing this compound. The bismuth and the iron that he melted together, appeared at first entirely mixed, but separated immediately afterwards. M. Karsten endeavoured to ascertain the influence of bismuth upon iron. With this object he made several refinery experiments, in which he added one per cent. of bismuth. It was necessary to stir the mass oftener than usual; but the iron produced was very good, and the bars had the usual strength. Therefore the bismuth did not produce any unfavourable effect, except that of retarding the refinery. This iron contained 0·081 per cent. of bismuth. According to similar experiments made by Hassenfratz, iron containing bismuth is easily forged. Yet, after the process of tempering, it was found to be hot-short and very brittle when cold. Cadet states that the density of this alloy is less than the mean of the two metals.

Iron and Calcium.—These metals combine, but, as it would appear, not directly, for Berzelius was unable to produce a well-defined alloy by fusing a mixture of chalk, pulverized carbon, and iron-filings.

Mr. Mushet made a great many experiments on these two bodies melted together in a crucible. The regulus was always brittle and hot-short, but it was not ascertained that the iron contained calcium. M. Karsten has often found calcium in cast-iron, but never in wrought-iron. He states that calcium behaves, with regard to iron, very much like the alkaline metals; and that, like them, it does not possess sufficient fixity to enter into combination with iron. Iron decomposes chalk at a high temperature, although the metals by no means evince any great affinity for one another.

Raw cast-iron fused with unslaked lime is deprived of its carbon. Some refinery experiments made with the additions of pure Carrara marble, have proved that the tenacity of the wrought-iron had been increased; but M. Karsten's analysis showed that the iron did not contain any trace of calcium, and that the action of the marble had been limited to the diminution of the quantity of phosphorus contained in the metal.

Other experiments of a similar character, in which a considerable quantity of carbonate of lime was added successively during the continuance of the experiment, proved that the iron had lost a portion of its tenacity, and had become less easy to weld. Nevertheless, this iron was neither hot-short nor brittle when cold, but it was traversed by longitudinal cracks. Analysis showed 0·1774 per cent. of calcium.

There is a kind of cast-iron obtained from ores requiring a large addition of lime, in which we find some traces of calcium. This earthy metal, however, does not combine with iron, according to M. Karsten, except under very rare circumstances.

Iron and Chromium.—Chromium has a very great affinity for iron, and the two metals form alloys in all proportions. Chromium is frequently met with in iron made from chromiferous ores, but it can be easily separated for the most part in the refinery. Thus the presence of iron greatly facilitates

the reduction of the oxide of chromium. Berthier states that the combinations which these metals form together, have more analogy with the sulphides, or the phosphides, &c., than with the alloys. He found that by applying a strong heat to a mixture of oxide of chromium and oxide of iron contained in a crucible lined with charcoal, these oxides are completely reduced, and a perfectly homogeneous combination of the two metals is obtained.

These compounds are generally hard, brittle, crystalline, of a grayer white than iron, and of very considerable lustre, less fusible, much less magnetic, and very much less soluble in acids than iron; the characters are the more prominent in proportion to the amount of chromium.

The alloy composed of—

Iron . . .	696·00	0·83	5 at.
Chromium .	351·82	0·17	1 ,,

is nearly of a silver-white, with a fibrous texture, not easily yielding to the file, and very brittle.

An alloy containing 0·60 of chromium and 0·40 of iron was obtained by the reduction of equal parts of sesquioxide of iron and of oxide of chromium, as a well-rounded button, with numerous cavities, and covered with long, interlaced, prismatic crystals. Its fracture presented a similar crystalline texture. Its colour was whiter than that of platina, and it was so hard that it cut glass as easily as a diamond, and so brittle that it could be powdered in an agate mortar: this powder still retained a metallic lustre. It was little affected by strong acids, or even by boiling with nitro-hydrochloric acid.

M. Merimée, with the aid of a very intelligent cutler, tried two different alloys prepared by M. Berthier, the one containing 0·010 of chromium, the other 0·015. Both forged extremely well; the former indeed appeared more easy to forge than pure cast-steel. Blades were made out of them for a sword and razor, and both were found to be of excellent quality, their edges being hard and lasting. But the most remarkable characteristic was the readiness with which this alloy received a beautiful damaskeening when rubbed with sulphuric acid. This damaskeening presented an agreeable variety of veins of a very brilliant silver-white, resembling much that which is obtained from steel when alloyed with silver. The white parts, according to M. Berthier, are probably pure chromium, upon which the strongest acids have scarcely any action.

If the alloy of iron and chromium could be made serviceable in the arts, it may be obtained much more cheaply by substituting chrome iron ore for the oxide of chrome, which would be too dear. Chrome iron is very abundant, and is found in a great number of localities. To obtain from this ore an alloy very rich in chromium, it must be melted in a crucible lined with charcoal or with alkaline glass; or, still better, with vitrified borax, with the proper proportion of lime and flint: but to extract the maximum of chromium, a certain quantity of oxide of iron must be added to the flux.

In the neighbourhood of Philadelphia and other localities in the United

States, this ore is found in large quantities, and is exported thence to Europe. It contains—

Oxide of chromium	0·516
Peroxide of iron	0·372
Aluminum	0·097
Silica	0·029
	0·990

According to M. Karsten, we do not yet know the influence which a small quantity of chrome exercises upon iron. Hassenfratz found that iron which contained but a small quantity, could be easily forged, although it was a little red-short; but it was not brittle when cold. Chromiferous ores are very rare: yet, according to M. Karsten, chromium is found in cast-iron as often as titanium, but it would seem to be separated in refining the iron.

According to the analyses of Vauquelin, made upon red-short iron containing 0·6 per cent. of phosphorus and 0·4 of chromium, it seemed credible that the iron owed its bad quality to the latter metal. But M. Berthier's experiments, described above, throw much light on the nature of the compounds of these two metals, and on the best methods for obtaining them on a small scale.

Iron and Cobalt.—These two metals combine by fusion; and, according to the experiments of Brande and Bergmann, cobalt combines with iron in all proportions, particularly when cobalt preponderates. Cobalt, indeed, generally contains some iron, from which it is very difficult to separate it: and the alloy is said to be very hard, and to be as ductile as iron. Hence it would appear, that in small quantities cobalt cannot be injurious.

Hassenfratz confirms in many particulars the results obtained by other metallurgists. His experiments show that iron containing cobalt could be both forged and welded; and although a little brittle when hot, it was not so when cold. M. Garey thinks, however, that cobalt makes iron brittle when cold.

According to Berzelius, the alloy of these two metals is hard and magnetic; but the precise influence which different proportions of cobalt exercise upon the ductility of iron is not known. M. Berthier says that the alloys of these two metals have the same properties as pure iron, and are whiter.

Iron and Copper.—These two metals appear to have little affinity for one another; at all events, it is very difficult to unite them together directly. The refractory nature of iron is in general an obstacle; and by melting these two metals together, we often find the iron mechanically united in the form of grains with the copper. Their alloy, according to Berzelius, is gray, brittle when cold, and magnetic even when it does not contain more than a tenth of iron; and according to M. Lehmann, a forty-eighth part of iron renders copper magnetic.

Wallerius states that copper alloyed with iron becomes gray, brittle, less

fusible, like black copper, and magnetic. But the characters depend on the proportion, and more or less intimate combination of the two metals. The maximum of copper which can enter into alloy with iron, and the influence which it exercises upon the latter, are still undetermined. Mr. Mushet states that copper unites with iron in a greater proportion, as the latter contains less carbon: so that it would be impossible, he says, to obtain an alloy of these two metals by melting them in contact with charcoal. But by taking very particular precautions it is quite possible to prepare this alloy.

According to M. Berther, iron and copper cannot form a true alloy; but when the two metals are melted together at a high temperature, the cast-iron retains a small quantity of copper, which is not separated when the iron is refined. This agrees with the results obtained by M. Karsten.

Copper, according to M. Karsten, may combine with any proportion of iron. It is well known, he says, that copper augments the tenacity and hardness of iron. Rinmann, for this reason, thinks that it would make, with raw cast-iron, an excellent alloy for making anchors, mortars, anvils, cylinders, &c. 200 parts of gray cast-iron, and 10 of red copper in thin shavings, immersed in linseed oil, and submitted, with the addition of charcoal, to a very hot forge fire during twenty-five minutes, yield, according to Rinmann, a homogeneous metallic button, composed of iron 194, copper 6. This alloy is very hard; its density is 7·467. Rinmann recommends it for anvils, &c. His experiments show that 200 parts of copper and 10 of gray cast-iron treated in the same way, yield a homogeneous button very ductile when cold. With 16 parts of copper and 1 of raw cast-iron, Rinmann obtained a ductile alloy that was magnetic, and resisted the file better than pure copper; the surface and the fracture were of a fine red colour.

Finally, 8 parts of copper and from 1 to 4 parts of iron, gave alloys which were harder than the preceding, but not perceptibly more brittle, nor less coloured than copper. Rinmann asserts in his *Histoire du Fer*, that wrought-iron is rendered red-short by the presence of copper: elsewhere he states the contrary. According to Lavoisier, iron containing copper possesses greater tenacity than any other, and becomes brittle only in the stages between a brown red and deep red heat: above or below this temperature it can readily be forged. M. Berthier affirms, in like manner, that iron containing copper possesses great tenacity when cold, but that it is brittle when hot, and can be forged only when above a reddish-white heat, or below a cherry-red heat. It is probable, he says, that a large proportion of copper, one per cent., for example, would give the cast-iron additional tenacity, and make it better fitted to be employed in castings. This opinion supports that of M. Rinmann, already mentioned.

Iron has been found in some copper money of the time of Constantine.

Hassenfratz found that the alloy of these metals is red-short, and brittle when cold. But he has not stated the proportions of the alloy. Most persons employed in iron-forges have no doubt that copper makes iron red-short; that a small portion of this metal detached from the tuyeres by the negligence of the smelters, may injure the quality of the whole product of

the operation: or that a piece of copper money thrown into a blast-furnace is enough to deteriorate the whole of the iron it contains.

M. Karsten made some refinery experiments at some of the Silesian forges, by adding in the first place to cast-iron 0·5 per cent. of copper. The flame thereupon became green, during the whole of the operation. The metal was very good; the iron could be drawn without cracking, and bore very well the tests of strength; the copper did not seem to have affected its tenacity, either when hot or when cold. He recommenced the same sort of experiment with one per cent. of silver. There was considerable difficulty in working the metal.

A bar heated to redness and immersed in water, disengaged a blue coloured flame. Out of eight bars, six stood the tests of strength; the two others broke at points previously fissured. Analysis showed the presence of 0·886 per cent. of copper in the sample of iron just spoken of. M. Karsten hence infers that copper does not produce the injurious effects so generally attributed to it. He admits, however, that it diminishes the tenacity of iron more even than phosphorus, specially impairing its capability of being welded. It is worthy of remark, he adds, that cupreous iron, everything else being the same, requires six times more time to dissolve in sulphuric acid and in aqua regia than iron in its ordinary condition. M. Stengel infers from these experiments that it is to copper we ought to attribute the defect in every case where iron is brittle when hot, and deficient in welding capability.

M. Hervé made some experiments also, in 1827, to form an alloy of cast-iron and copper, but met, as he expected, with very considerable difficulties. The following was his mode of procedure:—He first melted 100 parts of cast-iron in a crucible, throwing in subsequently 4 parts of copper shavings. After keeping the fused mass some time over the fire, he poured it into a dry clay mould. But in consequence of the mould being damp, or from some such cause, the metal boiled with considerable violence from the moment it entered the mould, and some portions of the alloy were projected to different parts of the room. After it had cooled he obtained an ingot full of blisters, and as though pierced through at every part except at the extremities. Its fracture was craggy, lamellar, granular, with large blisters; at the extremities of the ingot it was granular, and wanted lustre. The colour was a bluish-white gray. Under the file it was of a grayish-white colour, and brilliant; under the grinding-stone, steel-gray and shining. The ingot, in other respects, presented no characters of copper; but the residue found at the bottom of the crucible was very cupreous. There must, then, have been at least a partial separation of the copper. The aspect of the fracture of the ingot, however, would indicate that a small portion of the copper remained in combustion with the cast-iron.

No one has yet succeeded in giving iron a covering of copper; or in covering it with a layer of this metal by the "wet method" except by the electro-depositing process. Veneering and incrustation have been tried with more success; but these operations, indeed, amount to no more than the liquefaction, by means of borax, of the copper which is intended to fill up the interstices made in the iron. The alloy of these two metals is met with native; it con-

stitutes, in a great measure, what is known as black copper; that is, unrefined copper extracted from sulphuretted ores of copper. Thus, the copper of Peru contains, according to M. Berthier:—

Copper	0·978
Iron	0·020
Sulphur	0·002
	1·000

and would appear to be black copper not refined. Very often it contains a much greater proportion of iron.

M. Berthier has made the analysis of scoria from various works for refining copper, and he has found that the residue of the refinery of Peruvian copper was composed of—

Copper	0·19
Iron	0·81
Sulphur	a trace
	1·00

The "matts" obtained by smelting roasted copper pyrites contain, according to M. Berthier:—

Copper	0·270
Iron	0·400
Sulphur	0·250
Earthy matter	0·080
	1·000

The very rich "matts" arising from the fusion of the preceding "matts" contain, after washing, according to Berthier:—

Copper	0·660
Iron	0·080
Sulphur	0·210
Earthy matter	0·050
	1·000

A multitude of small grains of metallic copper were found in them.

The "matts" arising from the fusion of cupreous schist also contain iron. The following is their composition according to M. Berthier:—

Copper	0·586
Iron	0·132
Sulphur	0·232
Earthy matter	0·006
	0·956

The "matts" arising from the treatment of the preceding "matts" contain:—

Copper	0·598
Iron	0·158
Sulphur	0·226
	0·982

They are obtained as thin plates of a metallic black colour, with a crystalline fracture, mixed with an infinity of very small crystalline grains of red copper.

There exists in the neighbourhood of Voltera, at Monte-Casteli, in Tuscany, a large mine in which variegated copper forms the principal ore. It is very compact, with unequal fracture, of a bronzed colour, gray coloured at the fractures while fresh, but of a shining blue shade, like the breast of a pigeon, after being some days in contact with the air. It consists, according to M. Berthier, of—

Copper	0·672	0·994
Iron	0·068	
Sulphur	0·214	
Gangue	0·040	

Which corresponds with—

Sulphide of copper	0·887	8 at.
Proto-sulphide of iron	0·113	8 ,,

M. Gerold mentions a specimen of magnetic iron from Mexico, where it occurs in considerable beds, and which, with a specific gravity of 4·9, is said to be very rich in copper.

M. Stromeyer found copper in the proportion of 0·001 to 0·003 in all the aërolites he examined.

Iron and Tin.—According to M. Dumas, tin enters into alloy with iron in all proportions. Heated to a high temperature they melt; but at a moderate heat a separation takes place—a species of liquation. At first a quantity of pure tin, more or less considerable, is melted; then tin alloyed with iron; and there finally remains a less fusible alloy, consisting of tin and iron in other proportions, the iron predominating. This operation is performed on a large scale to purify ferruginous tin. M. Berthier states that a very small quantity of iron is sufficient to diminish the malleability of tin, blemish its white colour, and render it hard. The very smallest trace is detected by the action of the magnetic needle.

M. Berthier says that the two metals enter into direct alloy when their oxides are heated with either charcoal or black flux.

The alloy composed of—

Tin	0·351	1 at.
Iron	0·649	4 ,,

is of a clear iron-gray colour, crystalline, and sufficiently brittle to be reduced with ease to an impalpable powder.

The alloy composed of—

Tin	0·50
Iron	0·50

is of a grayish-white colour, very brittle, with a granulated fracture. According to Messrs. Bergmann, Karsten, and others, by melting iron with tin, two distinct and definite alloys are always obtained: the one composed of 21 parts of tin and 1 of iron; the other of 2 of iron and 1 of tin. The first is very malleable and harder than tin, without being so brilliant; the other is not very malleable, and too hard to be pared with the knife.

M. Hassenfratz has also succeeded in directly combining tin with wrought-iron. He finds that iron impregnated with tin cannot be forged, and that it falls to pieces under the hammer. A sheet of tin placed between two sheets of plate-iron produces the same effect. M. Karsten made some experiments upon this subject in Siberia. They show that one per cent. of tin added to cast-iron renders the iron extremely brittle when cold; but it is by no means red-short, and can easily be forged when hot, giving, during the operation, white vapours, which condense upon the anvil and hammer.

The analysis showed only 0·10 per cent. of tin in this iron, the strength of which, however, was considerably diminished. The same quantity of phosphorus would not produce any sensible effect upon the quality of iron. M. Karsten hence concludes that tin is more prejudicial in iron than phosphorus. Cast-iron containing tin has a texture as fine as steel; it is very sonorous, will receive a very beautiful polish, and possesses great hardness without breaking so easily by a sudden concussion, and without rusting so readily as ordinary cast-iron.

M. Rinmann proposes to employ it for several kinds of ornaments, for mirrors, and particularly for bells, on account of its very great fusibility. He also found that all the alloys of iron and tin that he had examined, blackened the skin and linen like tin, and that they had also the same peculiar disagreeable odour even when containing only a very small proportion of tin. Oxide of tin, melted with iron, is reduced to the metallic state.

According to Messrs. Macquer and Leonhardi, a small addition of iron gives tin a beautiful polish. With one part of iron and two of tin, a ductile alloy is obtained, which is attracted by the magnet, and has a dark gray fracture. The proportion of two and a-half per cent. of iron will alone suffice to make tin magnetic. By melting together equal parts of tin and iron, a white brittle mass is obtained, of a density which is unequal, in consequence of some iron separating during the cooling.

Tin is a powerful solvent of iron: 20 parts of tin suffice to fuse 100 parts of iron-filings at a temperature which, without such assistance, would have been far from sufficient to produce that result. M. Hervé has sometimes succeeded in liquefying forged iron with only ten per cent. of tin. The first alloy presented the following characteristics:—Compact fracture, a clear gray

colour, and dull surface; under the file a steel-gray colour, and shining; under the grinding-stone, the same colour. This alloy was very hard and brittle; it wore out the file. Another alloy, formed with 100 parts of cast-iron and 1 part of tin, presented an even fracture, slightly granular; of a clear gray colour, and dull; under the file, of a grayish-white shining colour; under the grinding-stone, the same colour. This alloy was equally brittle and hard.

Tin manifests an affinity for iron at the temperature of fusion. It then attaches itself to the surface of this metal, and thus furnishes an excellent means of protecting it against rust. This is what is called tinning.

Sheet-iron covered with tin is called tin-plate, and serves for a great number of purposes. The metals form a true alloy at the surface, with a layer of pure tin over it. Tinned iron presents the same appearance as tin, having both its colour and brilliancy. It preserves the latter quality in the air better than tin itself, because, as M. Dumas considers, a galvanic action is kept up between the two metals, tin being negative in relation to iron. But, for the same reason, oxidation takes place much more readily wherever there is the smallest flaw in the coating of tin, for the galvanic action renders the iron more susceptible of oxidation than in the natural state. When the sheet-iron is very thin, it is quite penetrated by the tin, and becomes white at the interior, is more easy to cut, and more malleable.

Sheet-iron, intended for tinning, should be of the finest quality, and carefully worked by hammering and rolling. The sheets are immersed for some minutes in very dilute hydrochloric acid, then placed in an oven and heated to redness, to detach the scales of oxide. It is then a second time flattened between hard cast-iron rollers; again immersed for twelve hours in a sour lye, made by fermenting bran with water; then in water acidulated with sulphuric acid, and agitated for about an hour until quite bright. When this operation, which is called "pickling," is completed, the plates are immersed in water, scoured with hemp and sand, then immersed separately in melted tallow, and finally in melted tin. When removed from the tin bath the plates are drained upon an iron grating, and the superfluous tin removed by successive immersion in baths of pure grain-tin, grease, and again in pure tin.

Vessels and utensils of cast-iron are tinned by cleansing the surface of the metal with dilute hydrochloric acid or chloride of tin, and are then coated by rubbing the heated vessels with tin, or by immersing them in a bath of the melted metal.

The tin covering the plates of iron presents a perfectly smooth and bright appearance, but its texture is nevertheless crystalline, which becomes apparent when the outermost layer is dissolved by a weak acid. It then presents a kind of watered "moiré metallique" appearance, which is often very beautiful. The acid and liquid used for this purpose consist of 2 parts of hydrochloric acid, 1 part of nitric acid, and 3 parts of water.

The watered appearance is produced by the unequal action of the acid upon the crystallized portions of the tin. The size of the crystals depends much upon the rapidity with which the tin is cooled. The crystallized sur-

face should be immediately covered with a transparent varnish, either coloured or otherwise.

An alloy consisting of 5 parts of tin with 1 of iron, called "Biberel's alloy," is used for tinning copper; its density is 7·247, it is slightly malleable when cold, but brittle when hot, has a steel-gray granular texture, and may be cut with scissors; it is easily obtained by melting together tin and clippings of tin-plate. It is said to give a more durable coating of tin to vessels, and is not so readily acted upon by weak acids. M. Thenard suggests for the same purpose an alloy of 8 parts of tin and 1 part of iron. It is solid, brittle, with a fine close granular texture, of a whitish-gray colour, fusible a little below a red heat. It is obtained by heating iron and tin in a crucible, and covering the mixture with pounded glass.

Dr. Ure states that tinned iron applied between the joints of wrought-brass, moistened in the first place with a strong solution of sal ammoniac, forms an excellent solder, if care is taken to avoid too strong a heat during the operation.

When tin ores are melted in a reverberatory furnace, ferruginous tin and scoriæ are always produced, which, according to M. Berthier, contain a great deal of oxide of iron and a certain quantity of oxide of tin. The scoriæ, when rich, are re-melted, and again produce ferruginous tin. This is submitted to liquation; and by this means tin, with very little alloy, is obtained, and there remains on the hearth of the furnace an alloy containing a large amount of iron.

Iron, Copper, and Antimony.—According to M. Achard, antimony determines the combination of copper with wrought-iron: equal parts of antimony and iron, and four times as much copper, form an alloy which is metallic, of uniform texture, very dense, brittle, white, unchanged by the air, with a fracture like that of steel, but capable of being easily filed and cast. The alloy of these three metals is met with in the "rosette copper" of Hungary; it consists, according to M. Berthier, of—

Copper	0·992
Antimony	0·007
Iron	0·001
	1·000

M. Hervé tried to combine these three metals in the following proportions:—

Wrought-iron in pieces	100
Copper	38·7
Antimony	10

The object was to ascertain if antimony was a good agent for producing the alloy of copper with iron; and the result was unfavourable to the supposition. A little antimony combined with the iron, and somewhat more with the copper; but he did not succeed in dissolving the pieces of wrought-iron, and

they were taken out of the crucible enveloped in a crust of an alloy of copper with antimony, containing probably a small proportion of iron. He found the alloy had a rough fracture, was craggy, granular, porous, grayish-white, and had a tolerable lustre. Under the file, it was whitish-gray and brilliant; under the grinding-stone, steel-gray and brilliant.

According to M. Achard, antimony determines the combination of copper with cast-iron in the highest proportion. M. Hervé made five experiments to alloy these three metals in the following proportions:—

	Antimony.	Copper.	Raw iron.
1st experiment	0·65	1·33	0·65
2nd „	1·00	2·02	1·00
3rd „	1·33	2·66	1·33
4th „	1·42	8·57	1·42
5th „	5·00	26·24	5·00

The ingots obtained presented the following characteristics:—

1st Experiment.—Fracture rough; texture granular and close, of a dark aspect, dull. Under the file, deep steel-gray colour and brilliant; under the grinding-stone, grayish-white colour, tending slightly to yellow, brilliant. The ingot presented no appearance of copper.

2nd Experiment.—Fracture rough, striated, lamellar; of a bluish gray-white colour; slightly lustrous. Under the file, of a clear steel-gray colour, shining; under the grinding-stone, the same. This ingot did not present any appearance of copper.

3rd Experiment.—Rough, craggy fracture, striated, radiated, of a bluish gray-white colour; not lustrous. Under the file, grayish-white, tending slightly to yellow; lustrous. No appearance of copper in the ingot, which had also the appearance of being hard, stiff, and brittle.

4th Experiment.—Rough fracture, granular, not close; of a blackish-gray dull colour. Under the file, a steel-gray colour, brilliant; under the grinding-stone, a deep steel-gray, brilliant. It had no appearance of copper.

5th Experiment.—Rough fracture, granular, lamellar, of a bluish gray-white colour; not lustrous. Under the file, iron-gray colour, moderately brilliant; under the grinding-stone, steel-gray colour, brilliant. The fracture of this ingot presented also a small nucleus, of a reddish-white colour, which appeared to contain more copper than the other portion of the ingot, with the exception of a few cupreous patches near it.

M. Hervé infers from these experiments that antimony is a very good medium for alloying copper with raw iron, and more effective than even tin or zinc. It is clear, in fact, from the fourth experiment, that 1·42 of antimony sufficed to produce the combination of 8·57 of copper with 100 of cast-iron. The results of the fourth experiment are still more conclusive; for notwithstanding the nucleus and the cupreous patches which the fracture of the ingot presented, it seems that the greater part of the twenty-six per cent. of copper had combined with the mass of iron.

All these ingots were hard, moderately brittle; but that in the fourth experiment was less so than others.

Iron, Arsenic, and Nickel.—A compound of these three metals occurs native in the nickel ore called kupfernickel, consisting, according to M. Stromeyer, of—

Nickel	0·442
Iron	0·006
Arsenic	0·548
Sulphur	0·004
	1·000

The pure mineral contains 0·5599 of arsenic. According to M. Berthier, by heating the arsenide of nickel with iron in any proportions, obtained by the reduction of the arseniate in a crucible lined with charcoal, double arsenides are obtained, which are homogeneous, very hard, brittle, and of a grayish-white colour like cast-iron.

CHAPTER XVI.

ON WROUGHT-IRON IN LARGE MASSES.

The manufacture of wrought-iron in large masses cannot boast of a very early origin. Although we read in the most ancient of Books that Tubal Cain, before the Flood, was an instructor of every artificer in brass and iron, it would doubtless have puzzled even that great founder of the iron trade, had he been furnished with an order to make the large masses of wrought-iron required for a "Great Britain," "Persia," "Marlborough," or "Great Eastern" steam-ship; and he would have been equally at a loss with many modern craftsmen, had he been requested to forge a "monster gun," or a double-throw crank-shaft for engines of 1000 horse-power. Were he again permitted to visit the world, the mighty machinery at work on every hand would compel the admission, that his trade had made great strides during his absence. These advances in the manufacture of wrought-iron in large masses have taken place almost entirely within the present century, if not, indeed, within the last thirty years. Up to that period, the improvements upon Tubal Cain's (we presume original) inventions were of so limited a nature, that, in the year 1820, the manufacture of a shaft—say of about 6 inches diameter, and weighing 15 or 20 cwt.—required the concentrated exertions of a large establishment, and was considered a vast triumph if successfully accomplished; whereas we are now accustomed to forgings of 20 and 30 tons' weight, as matters of every-day occurrence, scarcely exciting the slightest notice. Nor do we stop even here: much larger masses will no doubt, ere long, be manufactured for the construction of iron ships, which in future years, owing to the increased size and strength of the plates, will be built upon a scale that would but recently have been deemed fabulous. This consideration, combined with the requirements of rapid communication, which demand more colossal engines, call for renewed energy in conducting this important manufacture.

It may, perhaps, not be out of place to mention here, as a fact having few parallels in other branches of the industrial arts, that, almost without exception, all the improvements that have latterly crowded upon each other in this trade have originated with the "hammermen" or workmen themselves, and have been worked without even the protection of an exclusive patent-right.

Our subject naturally divides itself into two chief heads, viz. the materials of which forgings are made, and the tools with which the manufacture is accomplished. We purpose treating of the latter first.

Description of Forge-tools.—A forge has necessarily three principal divisions, viz. the furnace, the crane, and the hammer; and they compose the

chief fixtures. The furnace (Fig. 1) is, in this country, of the ordinary reverberating description, strongly bound together with plates and binders of iron, of a proportionate size to the description of work intended to be performed. A very great deal more depends upon the furnace than might be supposed by those who are not thoroughly conversant with the practical working of one. Variations in the slightest detail in their construction or working are followed by such great differences in the results, that even a good and experienced furnaceman, if set to manage a strange furnace, will find some difficulty until he has made himself thoroughly acquainted with its peculiarities.

The selection of a proper description of fire-brick with which to construct the furnace is a matter of considerable importance. Without attempting to enter into the merits of different fire-bricks, we would observe that the question of expense is infinitesimal when compared with the consequences of using cheap and inferior bricks, which would be costly at the lowest price, from the great wear and tear upon them, and from the annoyance and loss caused by the often-repeated stoppages for repairs. It is, therefore, the wisest and best economy always to use the very best fire-bricks that

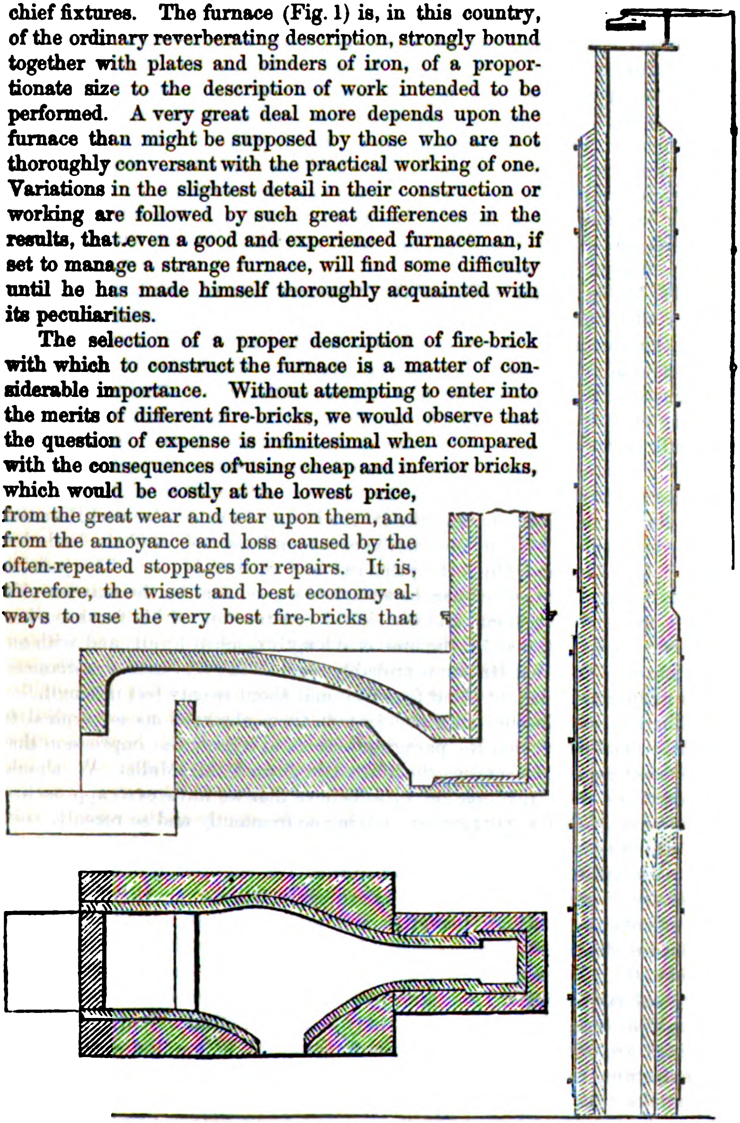


Fig. 1.

money can procure. In some cases where large work is intended to be made, a furnace, with a grate at each end, and having the stack or chimney in the centre, has been tried; but, as it has not been generally introduced, we presume it possesses few, if any, advantages over the ordinary furnace. In fact, for the largest forgings that have ever been made, furnaces with single grates have proved successful, where double-grated furnaces have failed. The sketch we have given in Fig. 1 is a furnace such as is generally used, and which is found very effective for the purposes required.

In America, where the chief fuel is anthracite coal, furnaces with closed ash-pits, and blown with a fan, are used, and which, we are given to under stand, answer very well.

Mr. Mallet, in his work on the "Construction of Artillery," page 114, states, that "at length the limit is found when with our present known modes of working wrought-iron (even with the heaviest and best appliances) we can no longer add to its size. The limit is reached by the failure of power to heat the mass, or the required part of it, to the welding heat. The time required for the piece to remain in the furnace to effect this, continually increases as its bulk grows, and with it the sources through which heat is lost and dissipated; but a certain proportion of iron is burned away, or melted from the surface at the part requiring to be brought to welding, as equals the weight of the 'slab' or mass laid on, and the labour is then in vain: the work, like that of the embroidery of Penelope, becomes an endless task, and the limit has been reached beyond which the piece can be forged no bigger. The point at which this limit is reached can be stretched a good deal by the extreme skill of the operative forgeman, and the skilful construction of his furnace; but, however great these may be, the limit is at length reached by all; and, with our existing tools, in Great Britain is probably reached in every case at a diameter (of a cylindrical mass) of about four feet, and about twenty feet in length."

There is considerable truth and force in these observations as applied to existing machinery; but the paragraph seems to convey the impression that we are not expected to exceed the limits laid down by Mr. Mallet. We should be sorry to endorse this opinion, or to believe that we have even approached the maximum size in our forgings, having so frequently and so recently seen that which is in one year deemed impracticable in the manufacture of forgings, accomplished with the utmost ease in the succeeding one; while the necessary requirements of that year are again followed by still further improvements, even where invention and mechanical skill had apparently reached their highest development. And so it will continue to the end of the chapter. We might as well attempt to obstruct the progress of the engineer, and say to him, "Thus far canst thou go, but no farther," as attempt to limit the sizes to which forgings may be made in future years. If larger forgings are required, and money is forthcoming to pay the cost of their manufacture, the work will not stand still for the want of workmen to undertake it, or machinery wherewith to handle it, however large it may be. The only real obstacle to the production of forgings of larger size is the cost; the bugbear set up in the above extract, that more iron is wasted than

is added, being but another mode of accounting for inexperience and bad workmanship.

Crane.—The crane is a very useful auxiliary in the working of the forge. Without its aid it would be impossible to fabricate those large masses of iron, the almost daily manufacture of which has ceased to excite surprise at their magnitude.

The crane (Fig. 2), as is well known, is composed, first of a strong upright, either independently fixed in a solid foundation in the ground, or dependent on the walls or roof of a building; next, of the top pieces, called "cheeks," and the "stays," to which is attached a winch of ordinary construction; and a strong pair of blocks, with a chain leading to the winch. It is necessary that the blocks should be capable of working backward and forward on the cheeks, which is technically called "racking out," or "in," from the fact that

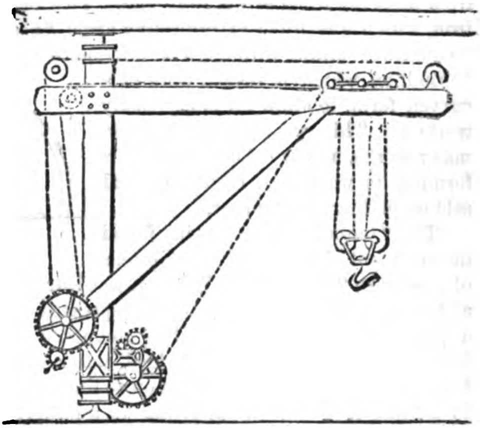


Fig. 2.

a rack and pinion-wheel are generally employed to effect the object. The crane must also be so placed that the centre is exactly equidistant from the centre of the furnace-door and the centre of the anvil, its use being to swing "the piece" from the furnace to the anvil, and *vice versâ.*

Cranes have generally been made of wood, although very few sorts of wood are capable of resisting the great heat to which cranes for forging are subjected. Others, however, have lately been made of iron, or of a mixture of iron and wood. Cast-iron, being comparatively brittle, is decidedly objectionable and unsafe, in consequence of the great weight they have to bear, and the excessive jar of the forge-hammer. There is less objection to wrought-iron, which if rightly proportioned, is we believe, the best material for the purpose.

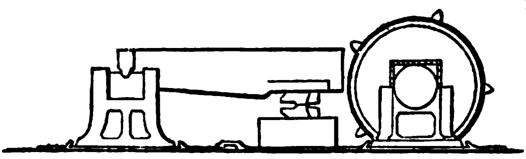


Fig. 3.

Hammers.—We now come to what is, perhaps, the most important, or, at any rate, what is considered the most important, tool in the forge, viz. the hammer; and we purpose giving a slight description of the various sorts in use at the present time, including the beautiful direct-acting tool known as

the Nasmyth or steam-hammer. We are unable, in the limits of this work, to consider the merits, or give any description of the various improvements that have been attempted on the original steam-hammer; some of them being confined to matters of detail, while others introduce defects so palpable, that we gladly return to the original Nasmyth.

The most ancient form of forge-hammer was probably that technically called the "tennant-helve" Fig. 3, known in France as the "Marteau frontal," from its being lifted at the front end. This hammer is a heavy mass of cast-iron, which was lifted by projecting arms, fixed in a ring of iron, called the "cam-ring," falling through a certain space by its own gravity. The pivots behind, on which it rested, were of a curved form, to allow its being easily worked. This was, and still is in many works, a very effective tool, performing its work with regularity, and seldom getting out of order.

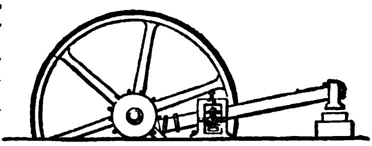


Fig. 4.

The "tennant-helves" being found inconvenient for certain descriptions of work, the "tilt-hammer" Fig. 4, was introduced. Instead of being raised at the front end, this hammer is depressed by a similar "cam-ring" from a part projecting behind. It is composed of wood and iron, the shank being of good tough oak, wedged into a ring in which it works; the hammer-head being also wedged on to the shank. The shank is surmounted by a beam of wood, which, acting as a powerful spring, gives greater force and rapidity to the blow. This form of hammer was peculiarly adapted to the "tilting" of the different sorts of steel.

Another improvement on the original "tennant-helve," was to lift the helve between the head of the hammer and the pivots on which it worked (Fig. 5), an advantage being thus given to the hammerman, which the tilt also possesses, by enabling him to go all round the end of his hammer. But the last and greatest improvement was that known to the trade as the "belly-helve" Fig. 6; a not very euphonious name, but one which, indicates the nature of the tool. It was lifted, as its name indicates, under the bottom part of the helve, by means of a "bray," which could be lengthened or shortened according to the size of the "piece" to be acted upon. With some of the largest size a very effectual blow is struck with a piece of iron of from 3 feet to 4 feet in

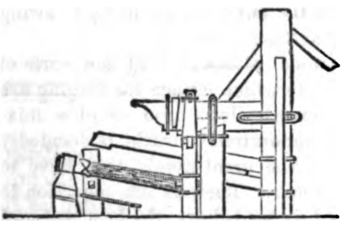


Fig. 5.

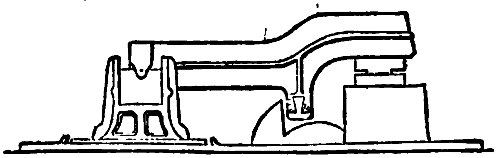


Fig. 6.

diameter—the "helve" being raised, and the "bray" being lengthened in proportion. This hammer also permits the hammerman to go completely round his hammer, to inspect the work under operation. For plain ordinary work it is not surpassed in efficiency, even by the direct-acting steam-hammer. It is of very great importance that the foundation be perfectly firm, and capable of resisting the force of the blows to which it is subjected. The most usual way of securing this end, is by placing under the anvil-block—which of itself is a very massive casting, weighing, with the cup upon which it rests, from twelve to fifteen tons—a considerable mass of timber, carefully placed and fitted cross-wise. This foundation must be strongly secured, for unless the anvil-block is very firm, a considerable portion of the blow will be dissipated, and its value lost.

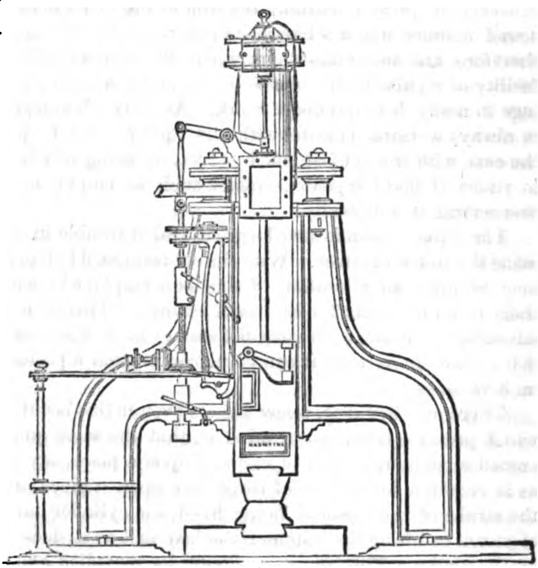


Fig. 7.

We come, lastly, to Nasmyth's steam-hammer, Fig. 7, a tool which has deservedly come into very general use. Although many of the very largest forgings have been made by the old-fashioned helves, especiallythe "belly-helve" above described; nevertheless, the invention has been of immense importance, not only to the forge-masters, but in many other branches of manufacture. The steam-hammer, like other great inventions, has its faults as well as its merits. The first great merit of the steam-hammer is, that it is a simple direct-acting machine, dispensing with much of the cumbrous wheel-work required with the old helves. It takes up little room, and requires no "gagger," as the attendant workman is called, who attends to the hammer. The presence of the "gagger" we object to, not so much on account of the expense, which is partly counterbalanced, in the case of the steam-hammer, by the necessity of employing an engineer; but on account of the almost insufferable torture from heat which the "gagger" has to endure: for if the "gag" is not inserted and the hammer stopped at the critical moment, a valuable piece of work may be damaged. Another of the excellences of the

steam-hammer is, that the blow can be varied according to the size of the "piece" under operation, and the force of the blow required. This is not, practically, such a great advantage as might at first appear; but in small works it is of considerable importance. We would, however, ourselves rather see the different sizes and classes of work effected under different sized hammers—with hammers perfectly proportioned to each description of work. Excepting in very large establishments, however, where there are a considerable number of hammers employed, this cannot always be accomplished. The consequence is that the hammer is used more as a squeezer, frequently crushing the iron at the heart instead of drawing it in a sound manner under a hammer proportioned to its size. Where the works, therefore, are not extensive, or where the number of hammers is limited, the facility of regulating the stroke by the steam-hammer is an important advantage in many descriptions of work. Another advantage is, that the hammer is always working parallel with the "piece" under operation, which is not the case with the old-fashioned helves, in using which the hammerman has to resort to many ingenious plans, such as employing thickness pieces, for overcoming this difficulty.

The hammerman is saved a great deal of trouble in regulating his tools, by using the steam-hammer. With the old-fashioned helve, almost every different heat requires an alteration of the tools employed; with the steam-hammer there is no necessity for any such change. This of itself is a considerable advantage. With the Nasmyth hammer he is also enabled to work on each side of the hammer, as it can be placed in such a position as to be accessible on both sides.

There are, however, a few defects even in this beautiful tool; and the first which presents itself to our mind is, that the same quantity of steam is consumed in striking a blow of one foot upon a piece, say of three feet diameter, as is required for a blow of three feet upon a piece one foot diameter; for, the stroke of the hammer being fixed, the cylinder takes the same quantity of steam in lifting the hammer the last foot as it does in lifting it the whole of the stroke. This might, no doubt, be remedied by some arrangement for raising or lowering the cylinder according to the height of the "piece" upon which the blow is to be struck, which would be somewhat similar to the arrangement in operating with the belly-helve, already described. Another defect, but one which attempts have been made to remedy in some modifications of the steam-hammer, arises from the difficulty of swinging the "piece" to be operated upon, from the furnace to the hammer, one of the legs of the hammer being sometimes in the way. This difficulty might be overcome by allowing the hammer to stand upon one strong leg, which would in many cases be a considerable improvement. We have, also, a great objection to the amount of gearing connected with the working of the valves. They are certainly very beautiful, and of most ingenious construction; but in all forging tools it is desirable that the greatest simplicity, combined with the greatest strength, should always be the first consideration. Arrangements have lately been made, we believe, for dispensing with these valves, and introducing in

their place a simple balance-valve capable of being worked with great ease, and not so liable to get out of order.

We have thus given some slight description of the different hammers employed in a forge. It has not been our intention to enter into very minute details upon this subject, nor to advance any very decided opinion as to the relative merits of the different implements; for we are aware that opinions greatly differ upon these points. The improvements that have taken place in this description of tools during the last fifteen years, have been very great; but we are prepared to witness still greater developments of mechanical application in connection with this branch of the art.

Materials.—We now propose to give a short description of the materials consumed in the forge, the chief of which are the coals and the iron. It is of considerable importance that care should be used in the selection of the fuel for the manufacture of forgings, as great difference exists in this important mineral, some being very much more suitable for the manufacture than others. The best for the purpose is a strong, dense, durable coal, possessing a good body, and having a dull, dirty appearance. Coal with a bright clean look, easily broken, as a general rule is not suitable. Of course it is desirable that the coal should be as free from sulphur as possible, and that it should not contain any large proportion of those foreign matters which, having an affinity for iron, fuse on the bars in the shape of clinkers.

We now come to the consideration of the best description of iron for this manufacture. Scrap-iron is that most generally used; but, far from agreeing with the generally received opinion that it is the best, we think that it is the very worst description of iron for the purpose; and for more reasons than one. Engineers usually require, in their contracts with the forge-master, that their forgings shall be made from the best scrap iron; and it is, of course, the duty of the forge-master to comply with the terms of his instructions and contract. Let us first endeavour to see how this almost universal belief in the superiority of scrap-iron has arisen. At the time when small forgings were first attempted to be made as an article of commerce, the manufacture of English iron was in such an imperfect state, and the quality so indifferent, that large quantities of the best iron had to be imported from Sweden and Russia, and for a long time the scrap-iron *was* of a quality that could not be approached by English iron of the period. Since that time, the use of Russian and Swedish iron has been almost entirely discontinued, except for the manufacture of steel; the greater part of the scrap-iron now produced, therefore, is of a very different quality to that formerly known as best scrap-iron. This material was deservedly considered the most proper material for the manufacture of forgings that could then be procured; but it must be borne in mind that, at the date we speak of, the forgings were so limited in size that the practical evils resulting from the use of scrap-iron, which we are about to explain, were not so perceptible.

In the ordinary manufacture of bar-iron it is the practice, in most works, in order to obtain it of the toughest and best description, to work and re-work it several times over. The number of workings the iron undergoes is marked

by the number of "best" stamps that it bears, as "best, best best," "treble best," &c., each "best" indicating a better quality, an extra working, and with a correspondingly higher price. But this progressive improvement has its limits, as will be perceived, from a series of experiments which were instituted by the writer with the object of testing the correctness and limits of this improvement.

Taking a quantity of ordinary fibrous puddled-iron, and reserving samples marked No. 1, we *piled* a portion five feet high, heated and rolled the remainder into two bars marked No. 2; again reserving two samples from the centre of these bars, the remainder were piled as before, and so continued until a portion of the iron had undergone twelve workings. The following table shows the tensile strain which each number bore:—

No. 1	puddled bar	43,904	lbs.
„ 2	re-heated . .	52,864	„
„ 3	„	59,585	„
„ 4	„	59,585	„
„ 5	„	57,344	„
„ 6	„	61,824	„
„ 7	„	59,585	„
„ 8	„	57,344	„
„ 9	„	57,344	„
„ 10	„	54,104	„
„ 11	„	51,968	„
„ 12	„	43,904	„

It will thus be seen that the quality of the iron regularly increased up to No. 6 (the slight difference of No. 5 may perhaps be attributed to the sample being slightly defective); and that from No. 6 the descent was in a similar ratio to the previous increase. From these experiments it appears that scrap-iron, or any other iron, highly refined, is the very worst material for the construction of large forgings which can be used; and that if we take, in the first instance, a strong fibrous fresh-puddled iron, the ordinary workings required in the process of forging will be sufficient to improve it to the average maximum of strength required; whereas highly refined iron, such as Lowmoor or Bowling, although the very best description for many purposes, has already reached the highest point in its strength, from which it is more likely to be deteriorated by additional workings.

It may then be asked—how can we hope, with any degree of success, to manufacture large forgings, which require to be worked over perhaps a score of times, each working beyond a given number tending to vitiate the iron? We can conceive that this deterioration does not penetrate the iron to any great depth; that few forgings are heated more than six times in one place before fresh iron is added; and that the various layers thus successively added to the mass protect the under portion from the deteriorating influences of the successive heatings. It is also to be observed that any crystallization which might take place, commences from the outside of the mass; and as

this is the portion which is most immediately acted upon by the blows of the hammer, the fibre is elongated in a greater degree, and thus restored to its original quality. As a proof of this, we may instance the manufacture of the monster gun, which was built up in seven distinct layers, the forging of which took seven weeks.

At the meeting of the British Association at Glasgow, in September, 1855, "a question was raised in the mechanical section as to the causes of the deterioration of the metal of which the artillery of the present day was constructed. On this question a long and interesting discussion ensued, both in reference to the comparative weakness of cast-iron as now produced, and the adaptation of forged and malleable iron as being stronger and better adapted for this purpose. The accounts received from the Baltic and Black Sea of the bursting of guns and mortars of recent construction, indicated that something was wrong. These failures gave rise to conjectures on the part of the Government as well as of the public; and, in order to trace the cause of this apparent weakness to its source, an inquiry was instituted by the authorities at Woolwich; and subsequently the Association appointed a Committee to co-operate with Her Majesty's Government in the investigation of this very important question. In order that no time might be lost, the secretary of the section was directed to issue circulars to engineers, iron-masters, and manufacturers, requesting that they would forward to the members of the Committee such opinions and observations as they deemed advisable, in regard to the material itself, and to its treatment preparatory to the manufacture of ordnance."

It is to be regretted that these circulars were not made more general, and that more of them were not addressed to practical forge-masters; for we observe, among the replies elicitated, the name of one man only practically and intimately connected with the manufacture of large masses of wrought-iron; and his reply is the only one indicating any hope of success in the application of wrought-iron for ordnance purposes. All the other writers who noticed wrought-iron at all (for many passed it by without the slightest attention) most unequivocally condemned it, and came to the conclusion, that "the tendency to crystallization which the long-continued heating produces is such, that powerful ordnance *cannot* be manufactured advantageously from malleable iron."

It was, perhaps, fortunate that the manufacturers of the monster gun were not aware of the adverse opinions thus pronounced against wrought-iron for ordnance; otherwise, they might have been discouraged in their attempt, and what must now be considered the successful manufacture of large wrought-iron ordnance might have been postponed. The following table of the tensile strength of the iron before it entered into the composition of the gun; of the iron cut from it, and as it now is in the gun, both transverse and longitudinal to the grain; and of the borings from the gun, worked over again in different ways,—tends to show that, so far from deterioration or crystallization having taken place, the metal was improved by its long-continued heating and working:—

Experiment	Description of Iron.	Breaking strain in lbs. per sq. in.	Average.	Sample bars 4 ins. long elongated.
No. 1.	Original iron of which the gun was made	48·384	.	$\frac{1}{4}$ in.
No. 2.	Ditto ditto	50·624	49·504	$\frac{1}{4}$ in.
No. 3.	Cut across the grain from muzzle of gun	41·644	..	$\frac{1}{8}$ in.
No. 4.	Ditto ditto	43·904	..	$\frac{1}{8}$ in.
No. 5.	Ditto ditto	50·624	43·390	$\frac{1}{4}$ in.
No. 6.	Cut with the grain from muzzle of gun	48·384	..	$\frac{1}{8}$ in.
No. 7.	Ditto ditto	50·624	..	$\frac{3}{8}$ in.
No. 8.	Ditto ditto	52·864	50·624	$\frac{1}{4}$ in.
No. 9.	Borings from gun worked over with coal	60·584	..	$\frac{1}{8}$ in.
No. 10.	Ditto ditto	62·824	61·704	$\frac{1}{4}$ in.
No. 11.	Borings from gun worked over with charcoal	76·584	76·584	$\frac{9}{16}$ in.
No. 12.	Swedish iron as imported, $\frac{3}{4}$ sq.	60·584	60·584	$\frac{1}{4}$ in.

From the above experiments it will be seen that the original iron put into the gun was of no extraordinary strength, which is accounted for by the fact that it was designedly selected, in consequence of the experiments already quoted, from what is commonly known as "No. 2 iron," or iron once worked over from the puddling-process, though of considerable strength and body, and commercially called "common iron." This iron, after seven weeks' heating and shaping into a gun, was, as we have already stated, so far from being deteriorated by this "long exposure to great heat," as to be actually improved in quality; for we find that the average of the trials gives an increase of tensile strength from 49·504 lbs. per square inch to 50·624 lbs., both trials being longitudinal with the fibre or grain of the iron.

The strength of the iron across the grain can hardly be regarded as of much importance, although it exhibits a remarkable amount of cohesion, for it was laid in the direction of the strain, and therefore the cut transverse to the grain might have been expected to possess less cohesion in that direction than if the grain had been placed in its position accidentally.

If we follow this question further, and examine the result of working over again the borings from this forging, we find that the tensile strength is increased from 49·504 lbs. per square inch to 61·704 lbs. when treated with coke, and 76·584 lbs. when worked with charcoal; and we think with results such as these—without parallel in any English make of iron, even under the most favourable circumstances—we may be allowed to assert that the myth commonly called "crystallization from long exposure to great heats," does not apply to the fabrication of this the largest forging ever made. We have given these details to illustrate and enforce the preference given to puddled-iron over scrap-iron; but there is another very important reason why scrap-iron should not be used for the manufacture of forgings—scrap-iron is composed of many various qualities of iron, and all of them have their own special welding points. When worked together, one portion that is less refined is too much heated, and consequently deteriorated, before the more highly-refined portions are at a welding heat; and we are thus placed in the awkward dilemma of either burning the one, or of being unable to weld the other. It may be said that this objection is a mere theoretical one, and that, practically, no such difficulty

exists. This, however, is not the case, for the difference of temperature at which puddled-iron and a highly-refined iron weld is very considerable; although, from the difficulty of finding a really good pyrometer for these extreme heats, we are unable to give exact data in degrees. If any proof were required of this, which is a matter of every-day economy, it is only necessary to inquire into the heating of iron for our rolling-mills. It is a well-established fact, that, in the mixing of different descriptions of iron in the piles for that purpose, the hardest and most refined iron is always placed outside, and the puddled or common iron inside. Were a contrary practice pursued, and puddled-iron of ordinary quality placed at the outside, and the highly-refined or scrap placed in the centre of the pile, the outer or puddled-iron would be wasted and destroyed before the inner portion was sufficiently hot to weld.

We may also call attention to the various qualities found among scrap-iron, some being what are termed "hot-short," and others "cold-short." We have before quoted a writer on the subject of the manufacture of wrought-iron for ordnance, who has stated that the limit has been reached beyond which forgings cannot be made; assigning reasons for those limits according to his own ideas and experience, the principal one being the assumed difficulty of heating such large masses. Now, if we take strong puddled-iron in place of the "scrap," which has hitherto been the material generally used, we effect, as we have shown, a saving of say about 20 per cent. in the heat required to unite soundly the various slabs or portions of which the "piece" is composed; in other words, by this simple substitution of the material used, we increase, to the extent of about 20 per cent., the supposititious limits of the writer from whom we have quoted, but the accuracy of whose conclusions we challenge.

Manufacture.—But scrap-iron, though, as we have endeavoured to show, the worst for our purpose, is the material from which forgings are generally made; and we must say a word or two as to its preparation. It is necessary, in the first place, that the small pieces of scrap-iron should undergo a cleaning process. For this purpose, they are generally placed in a large drum or vessel, which is caused to rotate at a considerable velocity by machinery; and they are thus, to a certain extent, freed from oxide and various other superficial impurities, that would otherwise injure the material for forging purposes. In some works, where large quantities of scrap-iron are consumed for this and other purposes, the scrap is usually carefully selected; and none but blue and clean iron, pure as when it came from the manufacturer's hands, is permitted to be used for forgings, the rusty and dirty iron being set aside for conversion to more common purposes, such as the manufacture of "bar-iron," "grate-bars," &c.

The scrap-iron, having been thus cleaned or selected, is divided into lumps or masses of various descriptions, by being piled in quantities generally varying from 100 to 200 lbs. in weight on a slate or tile. These piles are charged into a reverberating furnace, commonly called a "heating" or "balling" furnace. After remaining about one hour and a quarter, they are sufficiently heated to

be forged out into slabs or "blooms." The piling of the iron is an operation requiring considerable skill and experience, for if the pile is not solidly put together, it will fall down in the furnace, and perhaps become attached to others. About ten to eighteen of these piles, according to their size, constitute a charge or "heat;" and a good workman will turn out six charges per day, or about 3 tons 10 cwt. to 4 tons. Larger descriptions of slabs are used for many purposes; and several of those described are again piled together, subjected to the heating process, and hammered to the required shape. In some forges the same workman "shingles" or hammers his iron from the scrap-pile, and heats it in the same furnace in which he heats his forgings; but this is by no means a judicious arrangement. It is much better, especially with large work, that there should be a division of these operations, and that a certain number of men, of inferior skill, and consequently of less value, should heat and "shingle" the iron for the first processes, and deliver it to the more highly-paid and skilful hammerman in a further advanced and more convenient shape. There is another, and by no means inconsiderable advantage to be obtained by this arrangement. A much larger amount of work can be accomplished with the same number of men and tools, than in the case where the two classes of work are completed by one workman. These slabs vary in shape and size, according to the nature of the work for which they are intended; and are delivered to the hammerman accordingly.

In large forgings, each particular piece requires different treatment, according to the shape and use for which it is intended. On this depends the question of the best manner of making it. For instance, a screw-shaft, which is subject to torsion, requires that the iron should be put together in a manner very different from the mode in which a crank or cross-head is prepared. We will take the case of shafts. The most ancient method of forging them was to take a certain number of slabs or plates of iron, made into a pile thus (Fig. 3)

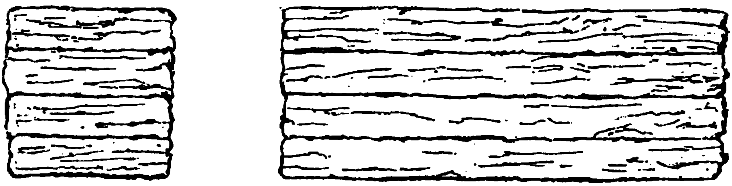


Fig. 3. End View. Fig. 3. Front View.

and after heating them, to hammer them into the round shape required. As it soon became necessary to make larger shafts, however, and as this pile could not conveniently be increased, an improvement was introduced, which consisted in taking a pile of slabs as before, and drawing a portion only of the mass into the shape required (see Fig. 4), leaving a lump on the end on which to place more slabs as needed; then drawing a little more at A to the required shape, adding more and more slabs as occasion required. This method is still practised at many works, and with considerable success; but

it requires the utmost care and circumspection, both in regard to workmanship and materials. This is the method by which shafts are generally made in the north of England and Scotland, and in America.

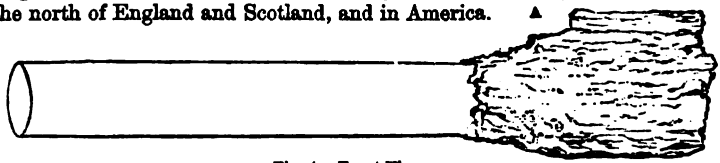


Fig. 4. Front View.

Another plan is to lay up a faggot of square bars sufficient to make the required shaft (Fig. 5). This is a considerable improvement upon the slab-plan, there being much less risk of false weldings and careless workmanship; and for this reason, when slabs are used, if the heat has not been sufficient to give a perfect weld to the iron, or if any oxide or dirt should intrude, the flaw or defect would run more across the shaft than in the faggot, where indeed any flaw from such causes would run longitudinally with the shaft, and consequently would not interfere in anything like the same degree with its strength. But this method also requires great care and attention; for if the faggot of square bars be made too large at one heat, the interior of the mass cannot be sufficiently heated to allow of the iron being welded at the centre. I have often seen broken steam-boat shafts which have never been united at all at the heart, the bars from which it was made being in the same shape and state as when they were placed in the faggot. To avoid this great evil it is necessary to be especially careful not to pack faggots too large at once, but to make, in the first instance, a moderate sized one, which, after being worked perfectly sound, has another layer of bars packed round it, and so on with further layers, until the necessary size is attained

Fig. 5. End View.

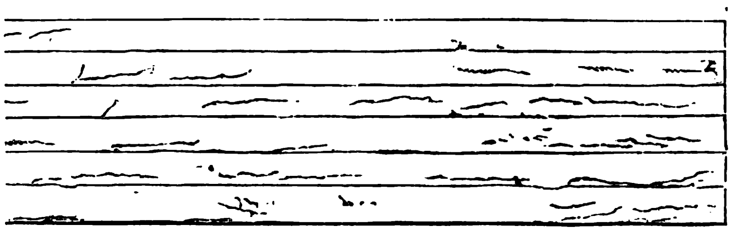


Fig. 5. Front View.

with perfect soundness. Thus Fig. 6, A being the original faggot after it has been made sound and solid, has the bars, as shown, packed round it; it is then again heated and hammered into the required shape.

The third method of manufacturing large shafts is commenced by mak-

ing a round core or heart, B, and taking bars of a V form to pack round it (Fig. 7). This is a method of forging railway axles which is frequently adopted. It was also the method adopted, with some variations, in forging the monster gun, at the Mersey Iron Works. In a previous page, we have given the tensile strength of the iron before it was forged into the gun, and its condition after undergoing that process; and it may be satisfactory if we give some details of the manner in which this large forging was worked.

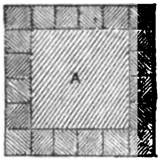


Fig. 6. End View.

We have already stated that it was built up in seven

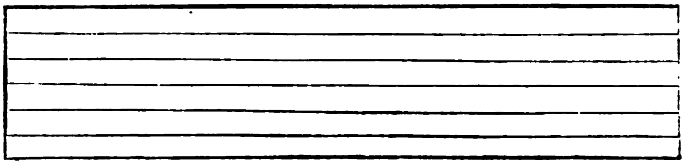


Fig. 6. Front View.

distinct layers or slabs, and that the forging occupied seven weeks; nor will this time seem unreasonable, when its dimensions and weight are remembered. The chief points to be considered by the designer of the gun were, to obtain sound weldings; to place the iron, with its fibres, in the proper direction for resisting the most severe strain to which it could be exposed; and to take care that, while working one part of the forging, other portions were not wasted under the action of the furnace, by burning or crystallization. The first operation was to prepare a core of suitable dimensions, and nearly the whole length of the gun. This was done by taking a number of rolled bars, about six feet in length, welding them together, and drawing them out until the proper length was obtained. A series of V-shaped bars were

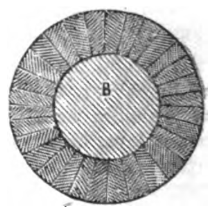


Fig. 7. End View.

Fig. 7. Front View.

now packed round the core, the whole mass heated in a reverberatory furnace, and forged under the largest belly-helve hammer. Another series of bars were now packed on, and the mass was heated again, and worked per-

fectly sound. Another longitudinal series of bars were still required over the whole length of the forging, which were added; and the mass now presented a forging about fifteen feet in length and thirty-two inches in diameter, but requiring to be augmented to forty-four inches at the breach, tapering down to twenty-seven inches at the muzzle. This was accomplished by two layers of iron, placed in such a manner as to resemble hoops, laid at right angles to the axis of the mass; and, after two more heatings and careful welding, the forging of the gun was completed. After each important addition, a "securing" heat was given to prevent flaws. It would be foreign to our purpose here to deal with this implement otherwise than as a mass of forged iron; its dimensions, as given by Captain Vandaleur in his report, are as follow:—

	Ft.	Ins.
Length	15	10
Diameter at base	3	7½
Diameter at muzzle	2	3¼
Diameter at trunnions . . .	3	3½
Length of bore	13	4
Diameter of bore	0	13·05

Its present weight is 21 tons, 17 cwt. 1 qr. 14 lbs.; the original weight, before boring, was 25 tons. The furnace employed was a reverberatory one; and the hammer, as we have seen, was the great belly-helve tilt-hammer, weighing 10 tons. As already intimated, the iron bored out of the gun was tough, sound, and perfectly homogeneous, some of the borings being curled like a watch-spring seven times round; and, when worked up again, it bore the test applied to prove its strength, as reported at page 320; and Messrs. Horsfall have the satisfaction of having produced a forging, which the scientific world had hitherto deemed impracticable.

Shafts have sometimes been made after another method, which we consider very injudicious. Many specimens of this mode of manufacture have come under the notice of the writer in the shape of broken shafts, where the unsoundness, arising from the method of working adopted, has been so great as to make it a matter of surprise that the shaft had done any duty at all.

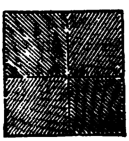


Fig. 8. End View.

The method in question was to forge four large square bars,

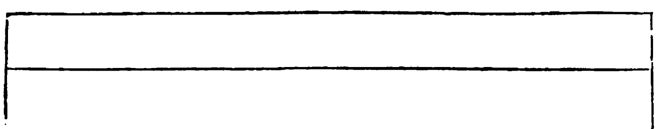


Fig. 8. Front View.

proportioned, of course, to the size of the shaft required; packing them

together (Fig. 8). This faggot was of such immense size, that the furnace and hammer employed were altogether insufficient to produce sound work; as a necessary consequence, when the shafts so made were broken, the fracture had an appearance similar to Fig. 9, being only welded on the circumference; while the four fissures at the centre were sufficient, in many cases, to receive a man's hand, while a rod of iron could be inserted from one end to the other.

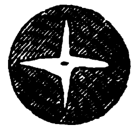


Fig. 9.

Crystallization.—A great deal has been said and written with reference to a supposed deterioration, or, as it has been called, "crystallization," of iron, when rolled in large masses, from long-continued and frequent heatings; it has also been asserted that the iron, while lying in the furnace, is continually attracting carbon from the grate, until, in course of time, it becomes carburetted, that is, reconverted into pig-iron. When this theory was first propounded, the writer determined to test its accuracy; and that in the presence of the gentlemen by whom it had been promulgated. A small knob, or corner, was accordingly detached from a large forging which had been over-heated, or burnt; it broke off with a large flaky appearance very similar to some descriptions of lead ore. This was pronounced to be very similar in its nature to cast-iron, and in the so-called crystallized state. Proceeding to the smiths' department, the iron was heated in the fire, and drawn down to about three times its original length. It worked well under the hammer; and when broken again in the usual way, was as beautifully fibrous as the iron from which it was originally made. This experiment led to the conclusion, that the iron acted upon was very different in its nature from cast-iron, and certainly failed in sustaining the crystallization theory.

It may be well, however, in the first place, to consider what is the meaning attached to this term—"Crystallization." It has been generally used to signify that the structure or composition of the iron has entirely changed its character and assumed a new form. Mr. Mallet, in his work before quoted (page 110), thus describes this change:—

"With the same iron and the same volume of forging, however, the size of the crystals appears to be larger and more developed in proportion to the time that the mass is maintained *hot* and in process of forging. This time is necessarily greater as the mass is so; and as the operation of reducing it to the required form is more complex or laborious. In fact, as in cast-iron, we saw that the crystals were larger the longer the mass required to cool; so in wrought-iron, they are larger the longer the mass is kept hot: and thus it happens that in very large and massive forgings, requiring often to be maintained perhaps for weeks, at temperatures varying from welding-heat down to dull redness, crystals are developed within the mass of a size tending materially to diminish, in some places, the average cohesion of the iron, where their planes of cleavage produce partial planes of weakness. The size of these crystals is occasionally surprising; the broadest and flattest planes of cleavage frequently running in the direction in which surfaces of the integrant slabs, or portions of iron of which the mass has been formed, have been welded together. The

author has observed crystals to deposit flat planes as large as the surface of a half-crown piece in forgings under seven tons weight."

We have little doubt that in many instances this statement is perfectly correct; we, however, at the same time declare our belief that cases are referred to where the greatest carelessness and inattention on the part of the workmen have been exhibited. We think, moreover, that some experiments which have taken place, and others which are still making, under the direction of Mr. Mallet, will induce him to alter his opinion on this point. To one of these we may here allude in support of this view: a sample bar has been planed out of the body of a large wrought-iron mortar piece made for him, and the sample shows a highly fibrous development, very different in appearance from the specimens described by Mr. Mallet in the above extract—a description, be it observed, which may be at any time observed in a forge on examining a piece of *burnt* iron, or in an exposed corner which has been subjected to very great but not necessarily continued heat.

It seems to us that all wrought-iron is, more or less, crystalline in its structure; and that the difference between what we call fibrous and crystallized iron only consists in the degree of fineness in the crystals, and perhaps in the manner in which they are laid together; the presence, also, of foreign matter, such as silicon, in some form, may also have its influence. Whatever the cause may be, however, it is known that a piece of good fibrous iron will break, under the smith's hammer, with a long silky appearance; if suddenly fractured by an irresistible blow, the same piece of iron will break crystalline, but the crystals will be very fine and close, and of a good colour.

In some experiments made at Woolwich, in the year 1842, to test the effect of shot against wrought-iron plates, and determine whether wrought-iron was a suitable material for ships of war, it was found that the toughest and most fibrous plate-iron, when struck by shot, was instantaneously crystallized; while the pieces struck out were so hot, that the fragments, even after passing a considerable distance through the air, could not be handled with the naked hand; in many cases the fracture had that blue appearance, which is indicative of considerable heat.

A 68-pounder wrought-iron gun burst with the first charge at Woolwich, on the 12th of July, 1855; on examination, the iron was pronounced to be crystallized, and its nature changed, by long exposure to great heat. This crystalline appearance was, most probably, the result of the very sudden description, as in the experiments with the iron plates; and, according to our view of the case, is traceable to bad workmanship. A considerable portion of the bars of which the forging was composed had never been welded at all; and no doubt the fracture commenced with these false weldings. The crystalline appearance, where the iron was torn from the solid mass, arose, at any rate, to a great extent, from the sudden fracture. Other causes, no doubt, assisted; among which the selection of iron too highly-refined may be included. From this crystalline appearance, the authorities of the Ordnance Department arrived at the conclusion, that large masses of iron, from long-continued

heating, have a tendency to crystallize, and lose the properties peculiar to wrought-iron. Acting on this hypothesis, they put a stop to what were called "Nasmyth's experiments" at Patricroft, pronouncing the manufacture of a wrought-iron gun of large size impossible—a theory which the successful manufacture of a much larger piece has since practically shown to be incorrect. As we have before shown, a bar of iron, planed transversely from a piece cut off the end of the gun, broke with a fibrous texture, and with a very slight tendency to crystallization; and that crystal by no means of a large character. This sample had never been treated or altered in the slightest degree since it was cut off the gun, and it would be pronounced "excellent best iron." A portion of this was afterwards rolled down to three-eighths of an inch round bar-iron, and it was bent cold in all ways without giving way in the slightest degree.

Having thus endeavoured to explain the meaning of the term "crystallization," let us now endeavour to trace the causes which produce this result.

The change in the structure of the mass of iron, when it occurs during the process of heating, is usually produced from the furnace being urged to a much greater heat than is necessary for welding the iron; in fact, the outside first, and, if the heat be not checked, the whole of the mass, is reduced to a pasty or partially fluid condition. The structure of the iron is thus entirely changed; and in the process of cooling the mass, crystallization takes place in the same manner as with other substances which crystallize in passing from the fluid to the solid state. Under these circumstances, the iron may be injured—in other words, it may be burned: but we are not to suppose that such a result is either inevitable or by any means common; on the contrary, the heat necessary to produce the evil is with difficulty obtained in our ordinary furnaces, under the most favourable circumstances.

Some years ago the experiment was tried at the Mersey Steel Works of fusing wrought-iron, with the idea of casting it into such shapes as "cranks," "cross-heads," and other forms required by engineers. They succeeded perfectly in obtaining excellent castings; but it was found that the deterioration of the structure of the iron in passing from the fluid to the solid state was such, that the work produced had little more strength than ordinary cast-iron. Of course, the manufacture was at once given up. But in the appearance of the fracture of the ingots resulting from Mr. Bessemer's experiments at Baxter-house, there was a great similarity between it and the results obtained in melting scrap wrought-iron.

Mr. Mallet, in his work (Note R, page 251), says:—"Late experience has shown me that in very large cylindrical masses of forged wrought-iron (*i.e.* of three feet diameter and upwards), amongst the other abnormal circumstances involved in their production, is that of their frequently rending or tearing internally in planes nearly parallel with, and about the axis, though not always in it, presenting a character similar to those described in section 217; the cause appears to be, that in the progress of cooling such a mass the exterior cools first and becomes rigid, while the internal portions are still red-hot and soft. The external parts contract as they cool, but they already grasp, in perfect contact, the still hot interior; the exterior therefore cannot

contract fully, but becomes solid under constraint circumferentially, partly itself extended in virtue of its compressing the still hot and soft interior. The latter at length also becomes cold and rigid; but its contraction is now resisted by the rigid arch of the exterior with which it is surrounded. The contraction of the interior, therefore, is limited to taking place radially outwards from the centre; and thus the mass rends itself asunder in some one or more planes parallel to the axis of the cylinder.

"In a cylindric mass of forged iron, varying from 24 to 36 inches in diameter, rents of 18 inches in width across a diameter were found, with jagged counterpart surfaces clearly torn asunder, and about ¾ths of an inch apart at the widest or central part; the fact is most instructive as to the enormous internal strains that must exist from like causes in cast-iron guns and mortars of large size."

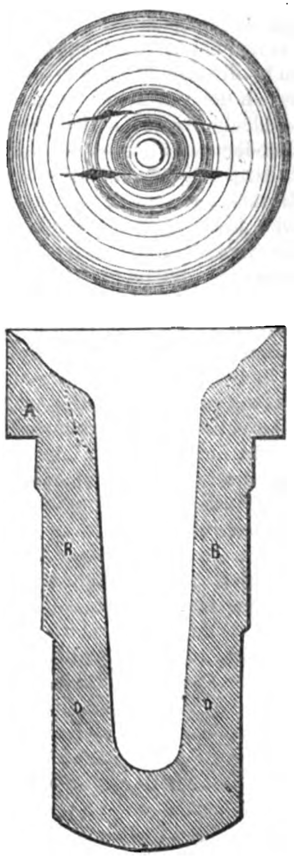


Fig. 10.

We give a sketch (Fig. 10) of the form of this forging, showing the faults or "fissures" that were found in it, and which no doubt took place from contraction after the piece had left the hammerman's hands perfectly sound.

When the forging was cooling, the part D would of course cool first; and as there was no great differential diameter between D and B, the differential contraction was not greater than the elasticity of the materials permitted; but the sudden and great difference in the diameters B and A caused the forging at B to be comparatively cool; whilst the forging at A had very considerable heat, the parts of the forging at B and D, being nearly cold, became rigid and unalterable, constituting a very strong arch, which prevented the forging from contracting in a regular manner.

If this forging had been of one uniform cylindrical shape, these fissures would not have taken place, as the contraction would have been uniform throughout at the same time the conducting power of iron is sufficient to allow of the heat passing from the interior to the outside with sufficient rapidity to prevent any fissure or unsoundness taking place in the forging.

Mr. Mallet proceeds to say—"It is probably from this cause that more or less hollowness is found in the centre of almost every large forging, greater

in proportion as the forging is larger. The difficulty is one not easily overcome. Very slow, and, as far as possible, uniform cooling of the whole mass in an annealing oven, suggests itself as one remedy; but this has disadvantages in enlarging the crystalline development of the metal, or providing a central cylindrical opening, so as to cool the circumference and the centre together."

Here, at last, we come to a tangible danger to be feared in the manufacture of large forgings, provided that due care and attention be not paid to its proper manipulation. But this danger is also common to castings, being created not by equal, but by differential contraction. There is nothing more to be dreaded in casting metals of any sort, but more especially those in which the contraction is great, than that any part of the casting should be suddenly reduced or increased in size. When this is the case, what the founders call "a draw" evidently takes place; and the same result is observed in large forgings, from the cooling of the smaller portions before the larger. In such a case as this, let us follow the practice of the engineer and founder, who, from experience and long practice, discourage such shapes as are found impracticable, and make such modifications in their plans as shall do away with these differential results.

Whilst Mr. Mallet's work was passing through the press, and without any communication from him, the maker of the forgings he mentions, after three failures, overcame the difficulty in the manner proposed; viz. by making a cylindrical opening in the centre, which allowed the interior of the forgings to cool as rapidly as the external ring, and which permitted the necessary contraction without producing fissures. To endeavour to overcome the difficulties incident to an important manufacture, which is still in its infancy, appears to be much preferable to the theory and maxims of the "How-not-to-do-it" school, who would sit quietly down under a difficulty without attempting to remove it.

In the Report, made by a Committee of the Franklin Institute, on the bursting of the wrought-iron gun on board the United States' steam-frigate "Princeton," the following facts were elicited:—

"1. The iron of which the gun was principally made was capable of being rendered of a good quality by sufficient working.

"2. From the state in which the iron was put into the gun, it was not in a proper condition for the purpose to which it was applied.

"3. The metal, as it existed in the gun, was decidedly bad.

"4. As to the manufacture of the gun, the welding was imperfect.

"These facts relate exclusively to the gun submitted to the examination of the committee, and they are derived from immediate experiments and observation. But besides giving these to the public, the committee felt themselves bound to express the opinion, that in the present state of the arts the use of wrought-iron guns of large calibre, made on the same plan as the gun now under examination, ought to be abandoned for the following reasons:—

"1. The practical difficulty, if not impossibility, of welding such a large mass of iron, so as to insure perfect soundness and uniformity throughout.

"2. The uncertainty that will always prevail in regard to imperfections in the welding. And

"3. From the fact that iron decreases in strength from long exposure to the intense heat necessary in making a gun of this size, without a possibility of restoring the fibre by hammering with the hammer at present in use in this country. At the same time the committee would not wish to be understood as expressing any opinion whether the construction of a safe wrought-iron gun upon some other plan is practicable or otherwise, in the present state of the arts, inasmuch as this subject has not been referred to them by the Department."

We are sorry that Mr. Mallet thinks it necessary to add to this Report, which he quotes at length in his valuable work on the "Construction of Artillery," the following remarks:—

"Nothing can more strikingly show the deteriorating effect of forging in large masses (however done) upon the tenacity of wrought-iron, than the fact of the preceding Report, nor the uncertainty of the process as respects welding. That the latter difficulty may be greatly mitigated (though it cannot be removed) by pre-eminent skill on the part of the hammerman, is proved by the success of the Mersey Steel Company in the duplicate perfected by them of the gun which failed for the "Princeton," and still more in the stupendous and apparently perfect forging they have now almost finished into a gun for the Government, no doubt by far the largest ever made in one piece, being 13¼ feet length of chase, 13 inches calibre, 14 or 15 inches thick at the charge, and about 9 inches at the muzzle, a solid shot of which will weigh 300 lbs." Mr. Mallet thus gives the weight of his authority (for which we entertain the greatest respect) to sentiments which, in our opinion, hardly need any further refutation than the facts which he himself mentions.

The several failures in the manufacture of wrought-iron guns should not be a matter of surprise; for it is hardly reasonable to expect immediate success in any new fabrication. How many failures, it might be asked, occurred before cast-iron guns were brought to the comparative perfection they have now reached? When we consider that an attempt has been successfully made to construct two of the largest guns ever attempted of wrought-iron, without having had any failure to record, we think it hardly probable that failure should occur where sufficient skill in workmanship is used, and with it added experience. It would, indeed, be somewhat strange, if, with additional experience, less successful results were to be obtained than in the first comparatively novel experiments.

One of the most common forms of real crystallization results from what is technically called "hammer-hardening." In the year 1854, at the meeting of the British Association in Liverpool, a paper was read by the writer of this article on the subject of crystallization of iron under certain circumstances. He selected a piece of good, tough, fibrous bar-iron, which he tested by treating in the usual manner. He then heated it to a full red-heat, and hammered it by light, rapid, tapping blows, until it was what is called "black-cold." After it was allowed to cool, he again broke it, and found

that the structure of the iron was entirely changed; and that, instead of bending nearly double without fracture, and, when the fracture did occur, breaking with a fine, silky fibre; an entire alteration had taken place, and the bar was of a rigid, brittle, sonorous character, incapable of bending in the slightest degree, but breaking with a glassy, crystallized appearance. By simply heating the bar to the same red-heat again, the fibre was restored exactly as before. This change in the structure of iron has been observed in railway axles and chains; and we believe that it is now customary, in some manufactories, to anneal such articles as are exposed to any jar or percussion, at regular periods, and with a beneficial result. Now this crystallization is particularly to be dreaded in forgings, for, unless great care is used, this error of "hammer-hardening" will often take place—sometimes from the vanity of the forge-man, who is naturally desirous to turn out a pretty well-finished forging; at other times, as is more generally the case, from the requisition of the engineer, who, without thinking of the result, wishes to have his forging delivered to him as nearly as possible to the finished size; and when, as is often the case, a very small allowance or margin is given between the forged and finished dimensions, the forge-man is under the necessity of working his iron much colder than is consistent with a due regard to strength. It is very true that some forge-men will work much nearer to the sizes given them than others, and still avoid the dangerous error of cold-hammering; but when certain dimensions are a *sine qua non*, inferior workmen, to keep anywhere near the mark, must "cold-hammer" their work; for none but a first-rate workman, and one who has every confidence in his own powers, dare bring his iron down to the required size at a full heat.

Some engineers, and we have known instances among the most eminent, in ordering their forgings, have made the remark—"Pray take care not to finish the work too cold, for we do not care for a fine polish to our forgings;" and this language we would urge all engineers to use. Such an instruction shows a true appreciation of the danger of cold-hammering, and a knowledge of this craft, which it is the object of this work to convey to all. But while we have a very strong objection to cold-hammered forgings, we should be sorry to be understood as encouraging that slovenly description of forging, which leaves the pieces so clumsy and unsightly as to require more than a necessary amount of cutting or turning. This is an error that ought also to be avoided. If proper care and attention were paid to the quality of the material used, as well as to the workmanship, we should have fewer break-downs in our sea-going steamers, and might, with perfect safety and great advantage, reduce the weight of those parts that are made of wrought-iron. In the selection of forgings, the cheapest are generally a long way from being the least costly; for the extra weight of material used, often brings the actual cost up to a level with the dearer, but better-finished and lighter forgings. Where cheapness of first cost is the rule, though accepted as the cheapest, it will, in all probability, be the dearest in the end.

In concluding this short paper, we would observe, that the opinions and facts here developed (although the result of long practical experience) have

been put together at a short notice, during the pressure of onerous business engagements, which permitted but little time to be devoted to the subject. The author does not for a moment pretend to treat this important subject in the scientific manner that it deserves; but, when requested, he gave his humble assistance to further, though in a slight degree, the development of knowledge on a subject which has hardly ever received the attention of those practically competent to write upon it; but which, he is convinced, is of great and growing importance to this country, as a national manufacture in which it stands proudly pre-eminent.

Should, however, the few remarks which we have put together awaken more inquiry, and further investigation of the subject, by those who have leisure and ability to pursue it, the author will rejoice that his humble endeavours have not been altogether in vain.

CHAPTER XVII.

STEEL MANUFACTURE.

The superior quality of steel produced by the British manufacturer from the best Swedish and Russian wrought or soft iron, has procured for him almost a monopoly of the steel trade of the whole world. Steel-works have long been established at Sheffield, Birmingham, and Newcastle-on-Tyne, and exist in a few other places. Sheffield, with its neighbourhood, is however the chief seat of this trade; and owes its first establishment, as well as its unparalleled development, to the possession of a number of natural advantages presented by no other locality in an equal degree. Among these may be named its situation near the south-western margin of the Yorkshire coal-basin, which contains all the varieties of coal for hard and soft coke, and also converting coal, which the different operations require. Between the Abdy coal, near Wath, eleven miles north-east from Sheffield, and the lowest of the beds near the town, there are no less than thirty-one seams of coal in a vertical section of seven hundred yards, sixteen of which seams are of sufficient thickness and commercial value to be wrought in different places. With the port of Hull, which receives the irons of Sweden, Norway, and Russia, Sheffield has long had river and canal communication, and latterly by railway also. Building-stone, capable of bearing the great heat of the melting and converting furnaces, is got near at hand, and also excellent clay for fire-bricks; within a few miles westward, lying at the bottom of the coal measures, and alternating with sandstone and shale, is found in several places that peculiar black clay for melting-pots, which is the only kind known which will bear the great heat of the steel-melting furnaces. These advantages would have been insufficient, especially in the earlier ages of its establishment, but for another, which made available and thereby increased the value of all the rest. We refer to the water-power of five small rapid manageable rivers, which, rising on the high lands of the western moors, converge towards the town. The Rivelin and Loxley join within a mile and a half on the north-west. and these are joined by the Don within a mile of Sheffield. On the south-west, the Porter and Sheaf join close to the town, and they meet the other united streams within the town itself. The river now called the Don, proceeding towards Doncaster, has several steel-works upon it before reaching Rotherham and Masbrough, where were the celebrated iron and steel-works of Messrs. Joshua Walker and Co., now in the hands of different proprietors. Upon these rivers, tilts, forges, and other works required in the manufacture of steel, were erected long before steam-power was applied to similar purposes, and when water-power was necessary to the very existence of the steel trade.

We shall now state the object of each operation, and the way in which it is performed.

To understand the process by which the manufacturer converts bar-iron into steel, we must first consider the difference in the composition of cast-iron, wrought-iron, and steel. Wrought or soft-iron may contain no carbon, and, if perfectly pure, would contain none, nor indeed any other impurity; but this is a state to be desired and aimed at, but it has never yet been perfectly attained in practice. The best as well as the commonest foreign irons always contain more or less carbon, and occasionally present pieces so steel-rank (as some of the old converters call it) as to be capable of being hardened. Carbon may exist in iron in the ratio of 65 parts to 10,000, without assuming the properties of steel. If the proportion be greater than that, and anywhere between the limits of 65 parts of carbon to 10,000 parts of iron, and 2 parts of carbon to 100 of iron, the alloy assumes the properties of steel. In cast-iron, the carbon exceeds 2 per cent., but in appearance and properties it differs widely from the hardest steel. These proportions, although we quote them, are somewhat doubtful; and the chemical constitution of these three substances may, perhaps, be regarded as still undetermined.

There seems, however, no reason to doubt that in steel, carbon exists in chemical combination with iron, but in some much lower proportion than the carburet. In cast-iron, it is not impossible that it may exist in two states—namely, as a carburet diffused through the mass, and also in that state which with wrought-iron constitutes steel; for cast-iron has this property in common with steel, that, when cooled quickly by casting it into metal moulds called chills, as is done for rollers and the faces of tilt and forge-hammers, the surface of the cast-iron becomes nearly as hard as hardened steel; and cast-iron is also, like steel, capable of being softened by the process of annealing.

The conversion of wrought-iron into a substance resembling cast-iron, in many of its characters, by subjecting its particles for some time to a state of vibration, without any chemical change in its composition taking place, seems to indicate that the different properties of these three materials may depend on other circumstances, besides the proportion the carbon bears to the iron. Various other bodies, such as phosphorus, silica, sulphur, and manganese, occur in small proportions, and must be regarded as impurities in steel. Sulphur and phosphorus especially are highly injurious to the quality of iron, and are with great difficulty separated from it. Some have even considered manganese essential to steel; but where its action can be beneficial, it seems to be by entering into combination with silica and other impurities.

In those melting furnaces where manganese is used, it is put into the melting pot with the steel to the extent of two, three, or four ounces, and with it a little charcoal also, if the steel requires more carbon. When the steel is melted, the manganese, with other impurities contained in the steel, is found floating at the top as a greenish glassy scoria, which, being removed, takes those impurities along with it, and in that way improves the quality of those common kinds of steel to which, for the most part, its use is limited.

The best-marks iron contain no appreciable quantity of manganese, nor can steel made from them be at all improved by its use.

Cast-iron is described as "hard, brittle, fusible at a high temperature; but neither malleable nor capable of being welded at any temperature." This, as a general description, is true; but must now be taken with due allowance as to the brittleness, for we see in Sheffield every day articles of cast-iron, which were brittle when cast, made soft by subsequent annealing. The most extraordinary results are produced in this way by Mr. John Crowley, who has paid great attention to the chemistry of this difficult subject. He makes a great variety of articles used in machinery, which, when cast, are as brittle as glass; but after being annealed for several days in close vessels, come out so soft as to bear bending and twisting as easily as the softest wrought-iron.

Wrought-iron is soft, tough, almost infusible, malleable when heated to a red-heat, and capable of being welded at a higher temperature.

Steel differs from wrought-iron in possessing this remarkable property, that when heated to a red-heat, and suddenly cooled by being plunged into cold water, or by any other method, it acquires a great degree of hardness. If the steel be converted into what is called a melting heat, it will by this treatment be made hard enough to scratch glass. This extreme hardness may be reduced to almost any degree of softness required by gradually heating the steel (after having rubbed part of its surface bright), and observing the change of colour produced by the commencement of oxidation. This operation is called tempering. The first visible tinge of yellow somewhat increases the toughness, without perceptibly reducing the hardness. A deeper yellow, approaching to orange, is a suitable temper for razors, penknives, and tools for turning, planing, chipping, or boring metals; a deeper orange is required for joiners' edged tools and table cutlery; and a blue for springs. If the heat be carried farther, while white succeeds to blue, the steel will be nearly as soft as when it left the hammer before it was hardened.

Thoroughly converted blister-steel is brittle, and can be easily broken by the blow of a hammer, or even by a smart blow on its edge, over the edge of an anvil; but after being heated and hammered, its tenacity is so much increased, that an unskilful person would have great difficulty in breaking it by any means he could think of. Taken in this state, and properly hardened and tempered, it is very elastic. At a red-heat it is malleable, at a white heat it may be welded either to another piece of steel or to iron, and at a still higher temperature it is fusible, and may be made into cast-steel by melting in a crucible.

To convert iron into steel, the English method is to take best Swedish or Russian wrought or bar-iron, and subject it for some time to a high degree of temperature in contact with small pieces of wood-charcoal in close vessels, so as totally to exclude the air. The quality of the Swedish and Russian wrought-iron brought into this country is distinguished by trade marks impressed on the bars. Certain of these marks, called hoop L, GL, and double bullet, are known in the trade as "best" marks. The British manufacturers have been supplied with them more than a century by Messrs. Joseph Sykes

and Sons, of Hull, through whom also they have received a great part of the make of several of the other marks known as second marks, some of which are nearly, if not fully, equal to those called best in quality. The second marks are W and crown, GF hoop S, JB and crown, gridiron, Steinbok, S and dots; and with these might rank one quality of Norwegian iron. These, with an occasional importation of less known marks, and a large quantity of the Russian iron CCND, belonging to Count Demidoff, made in different parts of his extensive estates, and which varies more than most other irons in quality on that account, were the chief sources of supply, and were sufficient to meet the demand up to the peace of 1815. It was the custom of some of the manufacturers of that day to break up their blister-steel with their own hands, to examine and apply it to the purposes for which they judged it to be best suited; and as it again came under their review in the subsequent processes of steel-making, and often also of being made into goods, they became thoroughly acquainted with the properties of the various marks in use, and considered, with reason, that their reputation as manufacturers depended upon the judicious application of the material.

So strong was the preference or prejudice in favour of the well-known marks, and the fear of loss of reputation which might follow the use of any new sort, that it would have been found almost impossible to introduce any other, even at a greatly reduced price, if it had been possible to increase the supply of the old marks.

Though the magnetic iron ore of Sweden is abundant, the quantity of iron that can be made from it is limited by the quantity of wood for charcoal that can be grown within a moderate distance of the works. What the steel manufacturers were very reluctant to do, was at length forced upon them by the necessity of the case; and iron made from the hæmatite ore of Sweden came gradually into extensive use.

In this change, which began to take place about 1820, Messrs. Cowie and Brandstrom of Hull may be regarded as the pioneers. The latter, a Swede, confined his labours chiefly to the selection of the best made irons in his own country, while his indefatigable partner had the greater labour of inducing the manufacturers to try them. He got some of their iron converted into steel, and got articles of all sorts made from it, which he exhibited as proofs of the uses which their irons were fit for. He sold small quantities of the steel to the manufacturers to try for themselves; and, after much opposition, two or three of the new marks so introduced began to have an established place in the market; but in that stage a new difficulty met the firm. Some of the old-established iron merchants contracted with the proprietors of the works for those marks, and they were lost to the introducers, who had again to begin with other new marks. They persevered, however; and by inducing some proprietors in Sweden to turn their attention to the making of a superior iron for steel purposes, furnishing them from this country with superior machinery, and making such suggestions as to their knowledge and experience appeared to be improvements, they were again enabled to introduce several other marks, some of which they lost as they did the others; so that,

on the whole, their success, while benefical to the trade, was not so remunerative to themselves as their industry deserved. Thus begun, a revolution was gradually but surely made in the iron trade with Sweden. Many manufacturers have improved their production, and every year has witnessed the introduction of new marks; and with this change came another. Formerly the trade was supplied through the Hull merchants only, who now indeed supply as much as ever; but, in addition, many of the largest concerns buy a portion direct from the makers in Sweden, in some cases contracting for the whole make of a forge.

While those changes were taking place in Swedish, a new mark of Russian iron *Kb* was introduced, which proved the most useful addition we have yet received for cast-steel; and, fortunately, there is a good quantity of it made. It ranks with CCND in quality, and some prefer it to that mark for this purpose.

Contemporaneously with these changes, and to complete the account of materials used for conversion into steel, it ought to be mentioned that British irons for such purposes as do not require a hard conversion, are extensively used; and some of them answer the purpose remarkably well. Of these the Low Moor and Bowling irons are perhaps the best—at least, they are the best known, and obtain the highest price; they have been in use many years for forks, mill-saws, slabs, and springs.

Of the different kinds of iron enumerated, the best and second marks made of the magnetic iron ore of Dannemora, which is nearly pure black oxide, owe their superiority over the other Swedish irons to their greater freedom from the contamination of foreign substances. Both these irons and the marks made from hæmatites are superior to the British for steel purposes, because both are made with charcoal only. The argillaceous iron ores of Britain are more difficult to reduce and to obtain free from sulphur than either of the others, and the use of coke further deteriorates their steel-making quality, as is made apparent by the experiments made on Swedish pig-iron when wrought into bars in England. Even Swedish blooms, which have been heated and welded in our coke fires, and drawn into bars, are found to be deteriorated thereby.

In one respect, British iron is better than the Swedish. It is made sounder and more free from flaws, the high temperature obtainable in our fires, and the great weight and excellence of the machinery in our large iron-works, enabling the ironmasters to do this.

The converting furnace consists of two rectangular chests, technically called a pair of pots, made of silicious freestone, capable of bearing a great degree of heat unchanged. The stone is cut at the quarry into rectangular pieces, all six inches thick, and so arranged as to form, when put together, two chests of the dimensions required. They are usually from twelve to fourteen feet long, and about three feet six inches wide and deep. The chests should be supported, even where the ground is tolerably favourable, upon about four feet of solid masony; for it is of the greatest consequence that there should be no sinking or giving way of the foundation, so as to crack the chests and admit air, which would spoil the conversion. The masonry should finish

with a course of fire-brick; and upon that again is laid cross-walls of fire-brick, ten inches thick and the same distance apart, upon which the chests will immediately rest, while the brick divisions form flues underneath them. The two chests are indicated in the engraving (Fig. 1), which represents the converting-furnaces at right angles to their length. The chests are placed eighteen inches from and parallel to each other; and the space between them is divided into flues, corresponding with those which pass underneath, up the opposite side, and at the ends of the chests, into the fire-brick vault which covers them all.

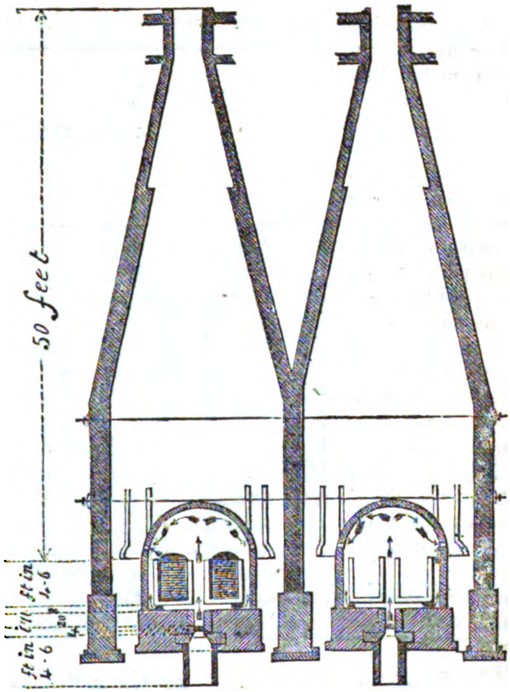


Fig. 1.

This vault has an arched opening at each end, large enough for a man to creep into when it is required to lay in iron or take out steel; at other times they are bricked up temporarily, and plastered with clay or wheelswarf. There are also two small temporary openings, one over each chest, through which bars can be put; and in these a piece of sheet-iron is laid when so used, with the edges turned up, to pass the bars more easily and prevent injury to the brick-work.

Out of the vault rise three small chimneys on each side opening into the large cupola, which carries the smoke to a considerable elevation, and prevents the wind from having much effect upon the draught of the furnace fire. The fire-grate is under the middle row of flues, and the whole length of the chests. It has a strong metal door at each end, which is kept close shut, except when a fresh charge of coal is being put in. The fire-brick work and also the chests are built with ground clay and water, mixed to a proper consistence, instead of lime mortar. The following ground-plan (Fig 2), represents the foundation-walls of two converting furnaces and cellars. Over the large

cellar is the iron-house. The walls, in this instance, are formed of rubble-stone, faced with brick, and the plan, with the dimensions, are taken from two furnaces erected in 1856.

The first thing the converter and men under him do, is to prepare the iron, the bars of which are principally from two to three inches broad and five-eighths to three-fourths of an inch thick, except where they are required for railway springs, and then they are made from three and a quarter to four inches in breadth. They are prepared by straightening the

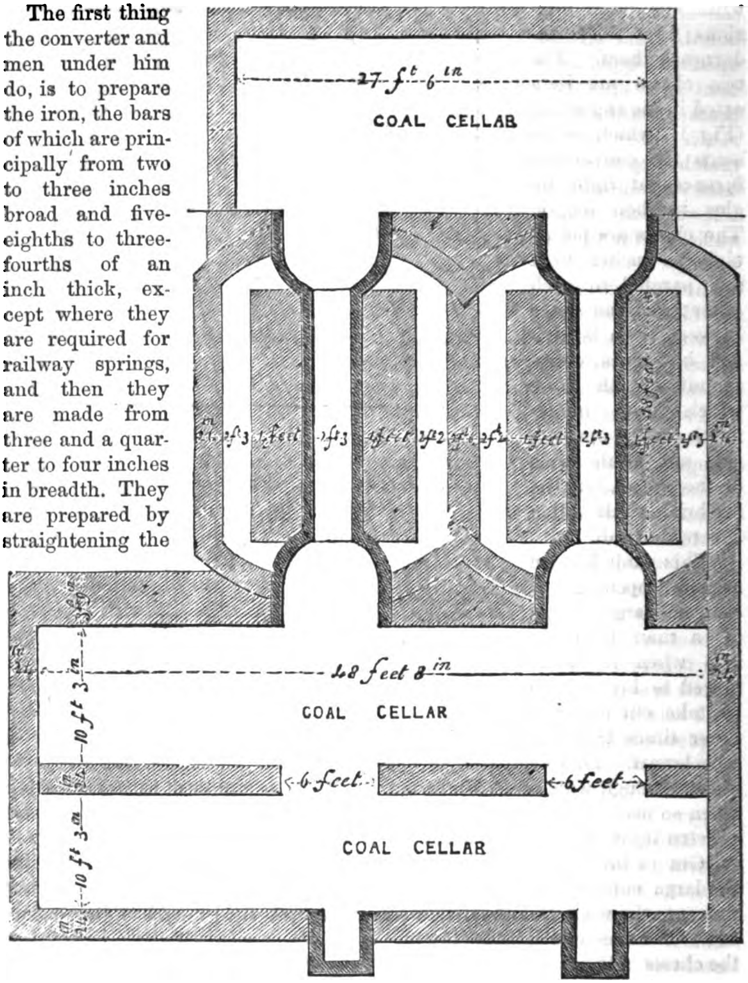


Fig. 2.

crooked bars, so that they may lie evenly in the chests, and by cutting such of them as are too long about three inches shorter than the chests, so as to allow for the expansion of the iron when hot. This done, the bars are

ready for laying in. The converter gets into one of the chests, and an assistant hands him through the man-hole a basketful of charcoal; so much of which as he judges sufficient he spreads upon the bottom of the chest, making it as level as he can with a straight-edged piece of board. The assistant now hands him bars through one of the small openings, broad or narrow, thick or thin, of one mark or another, if the heat is of different marks, as he is directed by the converter, who lays them upon the charcoal flat-side downwards, taking care that they do not reach either end by an inch at the least. With the short pieces he matches up those bars which are too short for the chest. The edges of the bars are laid so as to touch each other, or nearly so, without any particular allowance for expansion in that direction; the inequalities in the bars being sufficient for that purpose, seeing that the last bar of a course never fits exactly. A layer of bars being laid in the chest, and covered about half an inch thick with charcoal, bars and charcoal are then laid alternately, until the chest is nearly full, finishing with a thicker layer of charcoal than usual over the top. The other chest is filled in exactly the same manner, after which both are covered over with from four to five inches in thickness of wheelswarf, as the grit from the grindstone is called, and which may be had at the grinding-wheels for carting it away. This grit contains a portion of iron and steel, and their oxides, in minute division, intimately mixed with the grit, which seems to possess the valuable property for this purpose of undergoing a partial fusion when hot, and forming a kind of cindery slag, which perfectly protects the steel underneath from the action of the air.

Each furnace has a square opening of about five inches in the centre of the end of one of the chests, which is continued through the walls to the outside of the furnace, into which two or three bars, called tap-bars, are laid, partly in and partly out of the chests, but in such a manner that they can be drawn out when required. To prevent access of air to the chest, the rest of the opening is carefully filled up with fine ashes, well rammed in. The man-holes and small openings are now made up as before mentioned; a fire of coals, which had been previously prepared, is put upon the grate at both ends, and will now require constant attention day and night for six, seven, or eight days. The fire is raised gradually, and the intensity of it regulated solely by the experience and judgment of the converter, he having no instrument of the nature of a pyrometer to guide him.

The coal suitable for converting is such as will burn away in a good draught, leaving scarcely any residuum but white ashes, which fall between the bars into the ash-pit. That coal which in burning runs together into a mass of large cinder would not do at all, because in that state it would stop the draught from passing between the grate-bars through the fire. When fresh coal has to be put on, the fire is first levelled with a long coal rake, or rather long hook, being a rod of round iron with about four inches at the end turned at right angles; another smaller rod is occasionally passed between the grate-bars to clear away any obstruction. Large pieces of coal are thrown in chiefly by the hand, very little being used so small as to require a shovel; and when one

end of the grate is filled, the converter proceeds to fill the other, or another man does it at the same time. Each firing will take from 4 to 5 cwt. of coal, and will require renewal every 2½ or 3 hours; and a heat of steel converting will require, on the average, 12 or 13 tons of coal, or more, according to the size of the furnace and the time required. Most of the charcoal used is made by the pyroligneous acid manufacturers of the neighbourhood. It does not appear to be of any consequence what kind of wood is used for the charcoal—all kinds do equally well; but oak-billets burned in retorts, and afterwards ground or broken down to about the size of horse-beans, is the kind principally used, for no other reason, however, than that it is most easily obtained. Another kind of charcoal, called rammel, is made by burning the small branches in the woods; and some converters prefer it for those heats which do not require a hard conversion.

A furnace of the size generally preferred, will hold from 16 to 18 tons of iron. In larger furnacés, the steel cannot be so equally converted; and in smaller, the conversion costs more per ton. The iron is considered to gain about four pounds to the ton in this process; but this will depend upon the kind of heat used, whether a mild one for springs or a hard one for melting; but, after all, the gain in weight must only be regarded as an approximation: how much of it is due to charcoal-dust adhering loosely to the bars, and how much to carbon taken up chemically by the iron in forming steel, has not been determined with much accuracy. The weighing into and out of the furnace is never done with the nicety which the settlement of such a question would require.

Converting-furnaces are well worked if from fourteen to sixteen heats are got out of them in a year. When the fire has been continued so long that the degree of conversion desired is supposed to be nearly attained, one of the tap-bars is drawn out and the opening stopped up. When cold, it is broken; and by its appearance a judgment is formed of the state of the whole, and the firing regulated accordingly. In a few hours more a second bar is drawn, and the progress made in the interim observed; this is a further guide for the continuance of the fire for some time longer, or for allowing it to go out as the case may require.

Easy, simple, and certain as it appears for a person of experience to judge of the conversion of bar-steel by the appearance of its fracture, it is quite impossible to convey that knowledge to a stranger by any form of words; he must see the steel, and have all those differences pointed out to him before he can distinguish between hard and soft steel for himself.

The whole quantity put into a converting-furnace at one time is called a heat of steel; and according to the degree of carbonization required it is called a spring-heat, a cutler's-heat, a shear-heat, a file-heat, or a melting-heat. When the fire is let out, the furnace requires no attention for three or four days. By that time the man-holes may be opened to allow a draught of air through, to hasten the cooling; and in a few days more it will be cool enough for a man to enter in order to break the covers off, and take out the steel, which is generally done while the steel is still too hot to be taken out with the bare hands. The men's hands are protected in doing this by several

thicknesses of coarse cloth. Some of the charcoal, when the small dust is sifted from it, will be fit to use again, mixed with fresh charcoal.

Steel obtained by this process is never quite equally converted. Near the bottom and sides of the chests it is more carbonized than in the middle; and this is true also of every single bar, the external being more converted than the internal parts. A good converter can produce more uniformity in the whole heat than might be expected, by laying the thinnest bars where he knows they will get the least fire; or if the heat consists of marks of different kinds, and equality is desired, he will lay the poorest irons in that situation. It often happens that the same heat is intended to serve more than one purpose—for example, to be made into bar-steel files, and shear-steel; in that case the file-steel should have the most conversion. Bar-steel is also called blister-steel, on account of the blisters raised upon it in this process. Large irregular blisters may be taken as an indication of inferior iron. When the iron is uniform, the blisters are more uniform; but still vary from small pimples to half or three-quarters of an inch. This refers to steel made from foreign marks only. Little reliance, however, must be placed on the size of the blisters as indications of the quality of steel; for if small blisters were a proof of quality, steel from British iron would be better than best marks.

The blisters are doubtless owing to some impurities in the iron, which in the furnace take the gaseous form, and raise the blisters by the force of their elasticity. What those gases are, is unknown; but it is known that whatever the impurities, they are got rid of in the crucible of the melting furnace when bar-steel is made into cast-steel, of which the following proof may be given:—For a certain purpose it is desirable to make the outside of a bar of cast-steel harder than the middle; and to do this, ingots of cast-steel may be drawn down under the forge-hammer to nearly the size required, and then the extra dose of carbon may be given by bedding them in charcoal in the converting-furnace, like bars of iron. Cast-steel so treated will have no blisters, and may be finished under the hammer.

When large-sized square bars are to be converted for the files called "rubbers," the carbon will not penetrate deep enough at once, nor will all the four sides be converted alike, but the two which lie upward and downward will receive the most carbon; so that on being converted the second time, the other two sides should be laid in that position.

When and by whom the present method of converting iron into steel began to be practised is not recorded. The oldest furnaces remembered by persons now living, were on the same principle as those in use at the present day: this would carry the method back about a century; but it is probably much older. The earliest furnaces we have any knowledge of were built entirely above-ground; and whatever the strength and thickness given to the walls, they were liable to crack from the expansive force of the heated materials, thus giving admission to air. Where the air could also get access to the steel, its effect was to spoil the entire heat. In most cases the admission of air takes place while the heat is cooling, and its effect upon the steel is completely to decarbonize it to a depth varying from the thickness of a

sheet of paper to the tenth of an inch from the surface. That this decarbonization has taken place may be known by the red colour of the bar, even without breaking it. When broken, the bar appears like the others in the centre, but with a skin of very bright, shining, and soft iron surrounding it, which is extremely tough and will not harden. All such bars must go into the furnace again to be reconverted.

Many improvements suggested from time to time by experience have been made in the details of the construction of converting-furnaces; but none so important as that of placing the working part of the furnace under the surface-level, thus making use of the solid ground to resist the expansive force of the heated furnace.

It is popularly believed that converting iron into steel is an expensive process, which may have arisen from comparing the price of best bar-steel with the price of British iron. Hence, several methods have been proposed for converting, all of which would so far exceed in expense the efficient method now practised, that it may be presumed their authors would never have published them had they known the small expense at which the present method is conducted.

In former times, when the furnaces were made to hold eight or nine tons, the charge for converting for hire was 50*s*. per ton. About forty years ago, when they held about twelve tons, it was reduced to 45*s*.; since then reductions have been effected to 40*s*., 35*s*., 32*s*., 30*s*., 28*s*., and 26*s*., which last may be the price at which whole heats of spring-steel is converted at the present time. Ends of bar-steel reconverting, and scrap-steel, are charged price and half, and double price, according to circumstances.

One of the most extensive uses to which blister-steel was formerly put was the making of files, for which purpose the loose parts of the bars (by which is meant the parts which were not welded sound in the making) were broken out, and the sound parts tilted to the proper size and applied to this purpose. These, when ground ready for cutting, would present no outward appearance of flaws; but the cutter's chisels would often penetrate parts which were unsound, occasioned, apparently, by a white powder embedded in the steel: to distinguish this from the effects of imperfect welding, it was called white-loose. It was a source of great annoyance to the file-makers by spoiling the appearance of their files, and causing them to be sold at an inferior price, as wasters. They complained of it many years, yet nobody cared to apply a remedy, though it admitted of a very simple one, and the case is cited to show how difficult it is to get people to change their mode of working; when at length, about twenty years ago, Mr. Ekman, an eminent iron-master of Sweden, came to Sheffield, and was shown some files in the cut state with this fault; he expressed an opinion that he knew what it was, and could send a few bars for trial which he expected would be free from it. He did so; they were converted, but not used until his next visit to Sheffield, when the trial was made in his own presence. The cause had been found and the remedy applied: the files were without white-loose. He then explained the cause of white-loose by saying—"In my country we use wood-ashes,

in the same way that you use welding-sand at your forge, when we weld blooms; and it is nothing but wood-ashes mixed with the iron. The bars I sent you I saw made, and would not allow the men to use ashes." This may be a useful hint to some other Swedish iron-masters even now.

Bar-steel from the converting-furnace is made into single shear-steel and double shear-steel, which will differ in quality and value with the quality of the bar-steel from which it is made, and the judgment and care of the person who selects the steel. This name was given to it because it was the kind used for the blades of shears, formerly employed for cropping woollen cloths. Single shear-steel is distinguished by a single representation of a pair of those shears, and double shear by two.

Another distinction indicating the hardness of double shear was adopted by Messrs. Walker. When harder than usual, it was double spur; and when as hard as it could be made, it was double spur and double star. The two latter never ought to be attempted in any but the best of the second marks.

Good shear-steel may be made by following the practice of a maker who had a high reputation for it, which was this:—He used GL, W and crown, and GF bar-iron, converted to a hard shear heat; broke the bars himself into pieces about sixteen inches in length, carefully examining both ends. Such as he judged unfit for the purpose were put into two different places—one to be reconverted, the other to be melted. That which was suitable was divided into four classes, according to the degree of conversion each had received. The lowest degree received a chalk-mark lengthwise of the bar, which was understood to mean that it was suitable for table cutlery. The next, being thoroughly converted, was fit for tools, and such as was sent as double shear into the country: this he did not mark. The next was harder, and would do for double spur, or for such small sizes of double shear as had to be tilted after leaving the forge. He marked this H, and the hardest HH. By this care in sorting the steel, a much better article, with a higher degree of uniformity, resulted than could have been produced by the indiscriminate use of the same marks of blister-steel.

With articles of large dimensions or otherwise difficult to produce, GL was his favourite mark, while W and crown stood next. The practice is to heat the pieces of bar-steel to a red-heat, and draw them under the forge-hammer to about $1\frac{1}{4}$ or $1\frac{1}{2}$ inch broad, by $\frac{1}{2}$ or $\frac{5}{8}$ths of an inch thick; six or seven of these pieces are laid one upon another, with one end in an iron hoop with a handle to it, while a wedge is driven in to bind them together. They are now put into a hollow coke-fire, urged by a soft blast, which admits of being regulated and heated gradually up to a welding heat: during this time the surface of the bars is covered with clay beaten fine, and applied during the heating to exclude the air and prevent oxidation. When heated sufficiently, they are placed under the hammer, and carefully welded together. Supposing this to be done at a forge worked by water-power, the hammer remains at rest while the steel is heating; when it is ready, the attendant at the shuttle-pole, as it is called, is told to draw the shuttle, which he does gently; and as soon as the hammer begins to rise,

the forgeman swings the heated bars upon the anvil before the hammer falls again. The speed of the hammer is regulated by throwing more or less force of water upon the wheel, which the forgeman directs. In welding, the speed requires to be very slow, the hammer being suffered to rest a moment between each blow delivered upon the steel. When the bars are firmly attached, the speed is increased, and the steel drawn down to about two inches square; the hoop is then detached, the end just welded taken hold of with a pair of tongs, and the other end heated and welded in the same manner. It is now single shear, and may be finished to any size required; if ordered for any flat size, such as 1½ inch by ½ inch, the flat way of the bar should run in the same direction in which the bars were laid together. This rule should hold universally, and with double shear as well as single shear-steel. To make single shear into double shear, the bar made as above described is broken in the middle, the two pieces laid together, and welded a second time, and again drawn to the required size. By this double operation, the steel becomes more homogeneous, and of a finer texture, from the mechanical elongation of the fibre; so that any instrument made from it will receive and retain a finer edge. But there is one disadvantage attending this second welding, which often, without great care, more than counterbalances any advantages to be derived from it, and which would deter many persons from employing double shear-steel in large square sizes, especially for making screw-taps, or for any similar purpose. They would be very likely to split down the middle in the hardening process, and from the following causes:—In the second operation, the finely powdered clay used in the first welding not only fuses and spreads on the bars, but running between them, there becomes imprisoned, thus preventing the necessary union of the bars. For this reason, where the size required can be obtained in single shear, it is more to be depended upon than the double shear, provided, of course, the best bar is used in the manufacture. When the size required is larger than can be obtained at the first welding, the extra size should be got by making it upon a staff. This is more troublesome, and requires the steel, to succeed well, not only to be of the very best quality, but to be equally converted. This operation is as follows:—The bar of single shear, which should be as large as it can be made in the first instance, is welded upon one end of a strong staff or bar of steel, which is to serve as a handle; the extra size being obtained by welding upon this steel additional pieces, one by one, singly.

The forge-hammer for this purpose should be 6 or 7 cwt., and water-power is preferable to steam, because the motive power being unconnected with any other machinery, it can be regulated so as to run slow for welding and fast for drawing. Where steam-forges are used, they are generally in connection with other machinery requiring an uniform motion, thus necessitating an uniform speed in the forge, which is not so well in shear-steel making.

Cast-Steel.—This invention we owe to Benjamin Huntsman, an ingenious and skilful mechanic, who, about the year 1740, appears to have perfected his invention, and begun to make the steel for sale which is now known as Huntsman's cast-steel in every civilized country of the world. It is said

that Mr. Huntsman first directed his attention to the making of a more perfect kind of steel than any then procurable, because he was annoyed by the imperfection of the watch-springs supplied to him in his business of a watchmaker; but this was probably not the moving cause, for he had less to do with watches than with clocks, smoke-jacks, roasting-jacks, and other mechanical contrivances, on which he spent much time and took pleasure in exercising his skill, but by no means to the exclusion of other subjects of investigation, for he was a man to whom information on all subjects was welcome. He had a high reputation as an oculist, and also for his knowledge of medicine; his advice, therefore, was much sought after; and thus he lived, at the time he made his experiments on steel, in the exercise of a kind of diffusive benevolence, at the village of Handsworth, near Sheffield, a respected and worthy member of the Society of Friends.

Mr. Huntsman's descendants have no written records of the early experiments made by him, and the amount of success or failure which attended them; but there have been found at different times, other memorials, which testify more impressively than words, that he shared the usual fate of inventors in repeated losses and disappointments. These memorials are in the form of many hundredweights of steel, found buried in the earth about the manufactory, in digging foundations for buildings or other excavations; and it is in all the states which might be expected from imperfect melting, crucibles giving way, &c. From the situation in which it is found, it would appear that such failures were regarded by him as so much spoiled steel, of which nothing could be made, and it was buried in the earth as waste.

Now that the casting of steel is become the most important of our local branches of trade, and everything required for the successful practice of it provided in abundance, it is not easy for us to appreciate the difficulty of the first attempt. Mr. Huntsman had to invent the furnace and find out the materials it should be built of;—to find something that in the form of a crucible would bear the heat and hold the steel, which no crucible then in use would do; to find what fuel would produce such a heat, and where it could be obtained. Ingot moulds were not then cast, nor hoops and wedges made to hold them together; nor, in short, any of those things done about a melting furnace with which we are so familiar; indeed, it is only when we try to place ourselves in imagination in his situation, that we become sensible how great his difficulty must have been; and yet his genius and perseverance overcome all, and steel-casting was in his lifetime in all essentials what it is now.

Mr. Huntsman having perfected his invention, was not of a disposition to make the greatest commercial advantage of it. He cared little for mere money making. The excellence of his steel brought him reputation and business; and what came in this way, almost unsought, he attended to with care, but he never condescended to push business by any of those arts which are now so common. It appears that about the year 1770, he removed to Attercliffe, in the parish of Sheffield, where the business has ever since been conducted. This would be when he was near 70 years of age, and six years before his death in 1776. His son and immediate successor attended to so much busi-

ness as the well-deserved reputation of the steel brought to him, without much exertion on his own part. One line of conduct has characterized the Huntsmans throughout, and is as strictly observed now as at any former period. They make steel of the best quality only. The differences between the process as Mr. Huntsman left it and that now employed, and hereinafter described, lay in these particulars. In his time, and many years afterwards, only one crucible was put into the furnace-hole—now two are put in; and his pots held about half as much as those now used.

He used a flux said to be of broken bottle-glass, not with the expectation, so far as is known, that it would in any way improve the steel, but only to make it melt more readily. Those who followed him implicitly, without knowing why, did the same, but others invented fluxes for themselves; and fifty or sixty years ago "fluxing the pots" was the grand mystery of some steel melters, who, considering themselves a sort of *Adepti*, would not allow their workmen to flux the pots, least they should obtain possession of the secret, and become *Adepti* also. They, therefore, performed that ceremony for themselves; but in process of time it was found that steel would melt very well without any flux at all, and the practice has been discontinued many years.

Mr. Huntsman's process was long kept secret, and was only revealed, say the popular traditions of Sheffield, by an act of more than doubtful morality on the part of a rival manufacturer; for the Huntsmans had now become leading manufacturers of steel. The workmen admitted were pledged to secrecy, and every care was taken to prevent its betrayal; but it was betrayed nevertheless.

One cold winter's night, while the snow was falling in heavy flakes, and all was darkness and gloom, the manufactory at Attercliffe threw its red glare of light and some of its reflected heat on the neighbourhood, and on an object of the most abject appearance who presented himself at the entrance, praying for permission to share the warmth and shelter which it offered. The humane workmen found the appeal irresistible, and the apparent beggarman was permitted to take up his quarters in a warm corner of the building. A careful examination would have discovered little real sleep in the drowsiness which seemed to overtake the stranger-visitor; eagerly did he watch every movement of the workmen, while they went through the operations of the newly-discovered process. He observed, first of all, that bars of blistered steel were broken into small pieces, two or three inches in length, and placed in crucibles of fire-clay. When nearly full, a little green glass broken into small fragments was spread over the top, and the whole covered over with a closely-fitting cover. The crucibles were then placed in a furnace previously prepared for them; and after a lapse of from three to four hours, during which the crucibles were examined from time to time, to see that the metal was thoroughly melted and incorporated, the workmen proceeded to lift the crucible from its place in the furnace by means of tongs; and its molten contents, blazing, sparkling, and spurting, was poured into a mould of cast-iron previously prepared; here it was suffered to cool, while the crucibles were again filled, and the process repeated. When cool, the mould was un-

screwed, and a bar of cast-steel presented itself, which only required the aid of the hammerman to form a finished bar of cast steel.

How the unauthorized spectator of these operations effected his escape without detection, tradition does not say; but it tells us that, before many months had passed, the Huntsman manufactory at Attercliffe was not the only one where cast-steel was produced. However that may be, the discovery of the elder Huntsman led to enormous results for Sheffield. There is no civilized country where Sheffield steel is not largely used, either as a finished piece of cutlery, or as the raw material for some home manufacture.

Pot Clay and Pot Making.—The best clay is dark gray, approaching to black; and when fresh broken, presents a very smooth shining surface. Such as have any tinge or streak of yellow, and break with a dull fracture, contain ochre, and are unfit for the purpose. Before suitable clay was found at Stannington, Crawshaw-head, and Ashby-de-la-Zouch, the Stourbridge clay cost at Sheffield four guineas a ton: it now costs less than half; and that found nearer, still less. The clays are generally used mixed; they should be carefully kept clean and dry. When required, one day's make is put into a tub or stone-trough and moistened equally, laid upon the floor, and tempered by treading with the naked feet, first in one direction then in another, moving the feet two or three inches at a time, frequently turning it over with a spade, and throwing the outsides into the middle, taking care that the whole gets trodden equally. This labour is continued six or seven hours, when that which had at first scarcely any adhesion, becomes a tenacious and ductile mass. The pot-flask or mould, and plug, are usually in the form shown in Fig. 3. The pot-mould is of cast-iron, with two ears cast upon it to lift it by. Its inside is the shape of the outside of the pots; it is turned smooth, and is open at the bottom as well as at the top. There is a loose bottom to fit, but not so small as to pass through, which has a hole in the centre three-quarters of an inch in diameter. When in use, it stands upon a low post firmly fixed in the ground, which has also a hole five or six inches deep in its centre. The plug which forms the inside of the pot is of lignum-vitæ; it has an iron centre, which projects through it about five inches, corresponding in size with the hole at the bottom of the mould. The clay for each pot is weighed, and about 24 lbs. is used for each, which is moulded upon a strong bench into a short cylinder. The inside of the mould having been well oiled with whale-oil, the clay is dropped into it, and the plug, also oiled, is forced into the clay; while the projection finds the hole in the loose bottom in the centre of the mould, which guides the plug. The plug is driven down two or

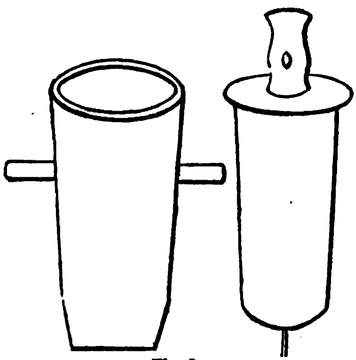


Fig. 3.

three inches by the blows of a heavy mallet on the top of the iron head; it is then taken out, to be oiled again, by putting a piece of round iron through the hole in the iron head to lift by, giving it, at the same time, a screwing motion. It is then driven by the mallet, while the clay, rising up between the plug and the mould, reaches the top. The clay is cut even with the top of the mould with a knife, and the plug taken out; the pot is then narrowed at the top by passing the knife round between it and the flask or mould several times, holding it inclined towards its centre. The mould is now taken and set with its loose bottom upon a small post fixed in the floor, and the man gently allows the weight of the mould to rest upon it, which pushes up the bottom with the pot upon it; and the hole being filled with a bit of clay, it is finished. When the pots are sufficiently hard to bear handling, they are placed to dry upon rows of shelves against the flues in the furnace.

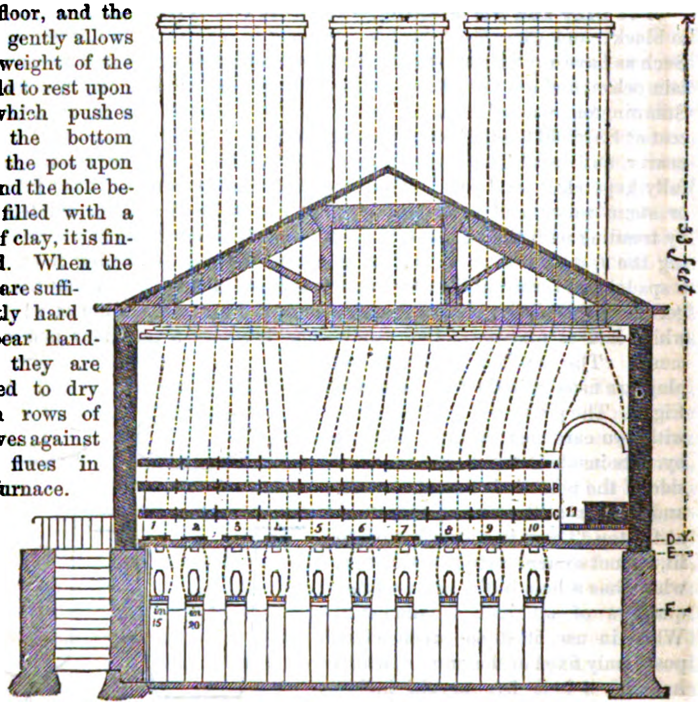


Fig. 4.

Furnaces.—The form of the melting furnace, and the direction of the fire and flue, will be understood from the accompanying engravings. Fig. 4 represents the section of a ten-hole melting furnace, showing the direction of the flues, and the form of the holes when about half worn, with one row of the pots in their places; 1 to 10 are the flues of the melting holes, each one of which is carried up separately, and lined with fire-brick to the top; 11, an open fire-grate; 12, the annealing grate, closed in front by a cast-

metal plate, rather broader than the depth of the melting pots; A B C three broad bars of iron, bolted to others at the back of the flues by cross-bars, to tie the chimney-stack firmly together.

The forms of the furnaces or holes are represented as they are when about half worn. When they become so wide as to waste the coke, the whole materials of the old melting-holes—represented on the cross section as occupying a space of 3 feet 6 inches, by 3 feet 3 inches—are taken out, and new ones built of a kind of natural faced fire-stone like flags, from 2 to 4 inches thick, cut into pieces 7 or 8 inches broad. These usually last four or five weeks before they want removing.

The cross section, Fig. 5, shows the position in which the two pots stand in the hole, and the cover in its usual position.

The cover-frame is made of wrought-iron 3 inches broad by ¾ths of an inch thick. A large fire-brick, made to fit, is held in its place by the movable bar of iron being pressed against it by two screws. The handle is of round iron, about 16 inches long. The furnace tops, upon which the covers rest, are of cast-iron an inch thick, cast in two parts. The plan, Fig. 6, is a common arrangement of the other rooms connected with a melting furnace. The two troughs in the clay-place are for wetting the clay previously to tempering it.

Some manufactories, instead of fire-stone, use what is called gannister or galliard-stone, ground: or the dirt from off such roads as are repaired with this kind of stone. In that case, wooden moulds are used of the form of the furnaces; and the ground gannister, moistened with water, is put round the mould, which is then drawn out. This kind

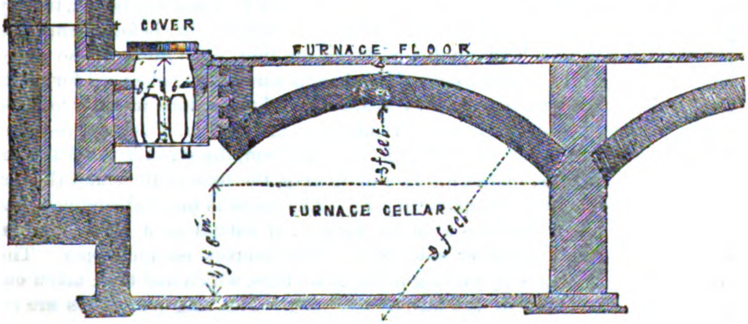


Fig. 5.

of stone is found in irregular masses, usually with fire-clay and carboniferous shale. It is argillaceous and very hard.

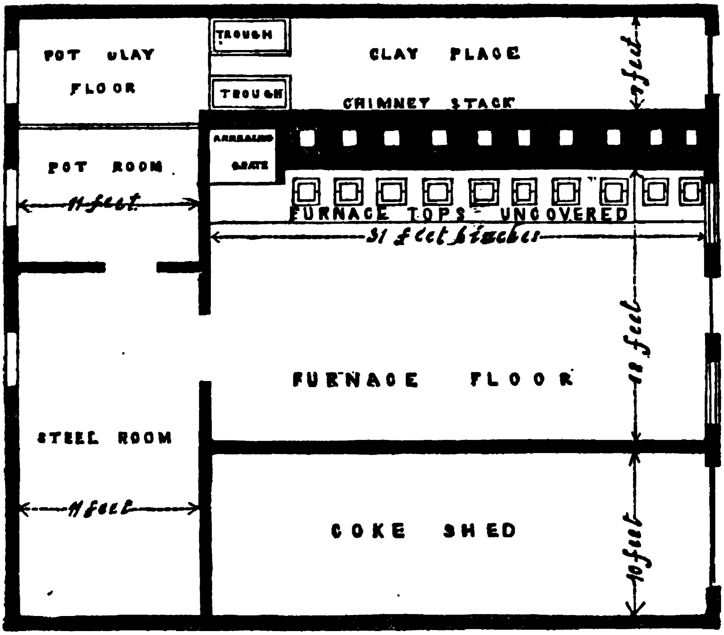


Fig. 6.

Melting Steel.—The preparations for melting commence the afternoon of the day before, by making a coal-fire upon the grate adjoining the annealing-grate. The annealing-grate must be large enough to hold twice as many pots as there are melting-holes in the furnace. If that number be ten, twenty pots are put inverted upon the annealing-grate, and the fire before mentioned put down the spaces between them, which are then to be filled up, so as to cover the pot with the small coke riddled from among the coke used for melting; and upon these again the pot-lids are laid. This is done in order to have the pots gently heated to a red-heat, ready for next morning. Each pot requires a stand and a lid, as represented in Fig. 7. In form, the stand is the frustrum of a cone about three inches high; and as upon the base of the stand the pot is to rest, they should correspond in size. The stand is made of common fire-clay, but the lid of clay the same as the pot; it should be a little larger in diameter, flat on the under side, and a little convex on the upper. The morning's work begins by putting in the grate-bars, which had been taken out the night before to clear the furnaces of slag. The slag and ashes are removed from the ash-pits. Each furnace has two stands placed in the proper

position upon the grate-bars; and upon the stands two pots, covered with their lids, from the annealing-grate. Some fire, with a little coal, and soon after some coke, is put on; and when this has burnt up, sufficient coke to cover the pots: when the furnace and pots are at a white heat, the steel may be put in. The steel having been broken and selected for the intended purpose, weighing say 34 lbs. for each pot, is put into pans of iron or steel plate. To charge a pot, the lid is taken off, and the lower end of a conical-shaped funnel (Fig. 7) placed over the pot, down which the steel is gently put by one man, while another with a long poker puts the steel in the best positions he can for making the pots hold it. The lid is then replaced; and the other pot being charged in the same manner, the furnace is filled with coke, and the cover put down. All the other pots are steeled in the same way. Afterwards, as the fires require more coke, the foreman, as he goes round looking at the state of the steel in the pots, orders how much coke is to be put into each furnace. While this is going on, other preparations are to be made. Steel has to be broken and weighed for the next charge, and moulds prepared for that in the furnace; those to be used are wiped with a rough cloth, and laid with their insides downwards upon two strong bars, raised a little above the floor; then a shallow iron dish is taken, and some tar poured into it, and fired, by having a piece of hot coke put into it; the dish is then held under the moulds, and moved about, to smoke them with the blazing tar. This is done to prevent the steel adhering; oil, or anything that would become gaseous, being inadmissible. The moulds are now put together in pairs, with two strong iron hoops round each, fastened by driving in wedges between the moulds and hoops.

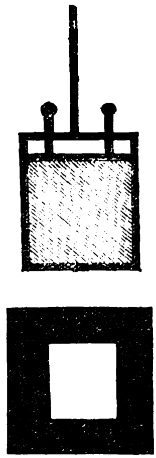


Fig. 7.

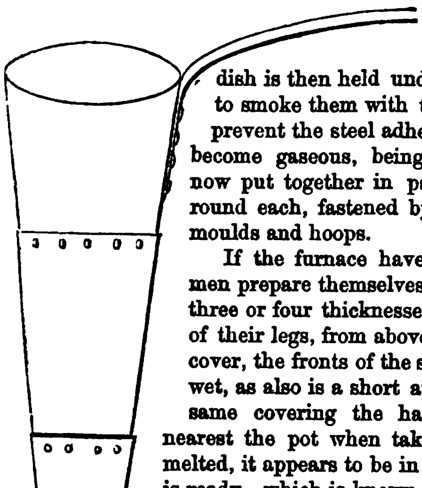
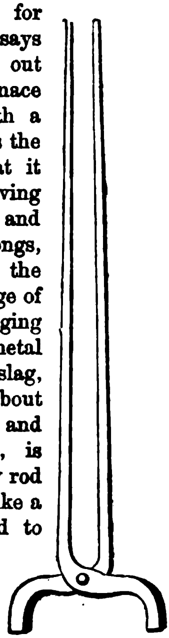


Fig. 8.

If the furnace have ten or twelve holes, two of the men prepare themselves for taking out the pots, by tying three or four thicknesses of sackcloth upon the front part of their legs, from above the knees down to, and so as to cover, the fronts of the shoes. This sacking is made quite wet, as also is a short apron, and a kind of sleeve of the same covering the hand and arm placed lowest and nearest the pot when taken out. Before the steel is well melted, it appears to be in a state of ebullition; but when it is ready—which is known by its clear surface and its resting in the pot without motion, and resembling, in its dazzling brilliancy, the sun on a clear day more than anything else—it is time to take it out.

Supposing the steel to be for tilting ingots, the moulds for which are nearly three feet long, two of the moulds are placed in a hole in the floor, made on purpose, about eighteen inches deep, and placed slightly inclined. All being ready for "teeming," the foreman says which pots are to be taken out first; the cover of the furnace is raised, and a man with a pair of tongs (Fig. 10) clasps the pot; and, ascertaining that it is not fast by slightly moving it, he suddenly stoops down, and taking lower hold of the tongs, raises himself, bringing up the pot and landing it on the edge of the hole; then, by a swinging motion, he moves it to a metal plate in the floor, where the slag, which generally adheres about the junction of the pot and stand, now firmly united, is dressed off by a long heavy rod of steel, shaped at the end like a chisel. The force required to do this is often very great, and severely tests the tenacity of the pots, which at that high temperature is surprisingly great, for they are never injured by this rough treatment. The pot is then moved close to the mould, where the man who has to pour the steel into it clasps the pot round the middle with the tongs (Fig. 9); the lid is taken off by the man who drew it out, and the steel poured gently into the mould, especially the latter part of it, which is done to prevent so deep a hollow in the top of the ingot as would be made if the steel were poured in too rapidly. The steel in contact with the cold mould becomes solid almost immediately, while that in the middle contracts as it loses its caloric; and the slow pouring is to fill the hollow thus occasioned, and prevent waste. While one is pouring, another man stands with a rod of steel in his hand, ready to stop from going into the mould any scoria which may float upon the top of the melted steel, of which there is a considerable quantity when manganese has been used, but little or none where good steel has been melted *per se*. As soon as the pot is empty, the lid is put on, and it is replaced in the

Fig. 9.



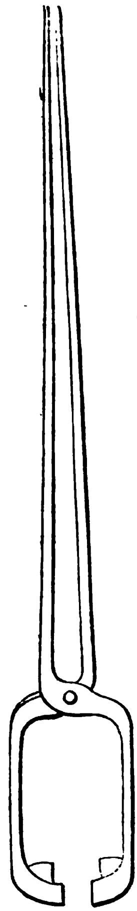


Fig. 10.

furnace; and the same having been done with the other pots, a quantity of coke is put in, and the hole covered. When one man has taken out his ten or twelve pots, the other takes out his number; and each hole, as the pots are replaced, receives a charge of coke, and is covered.

In a very short time, two moulds filled with steel may be taken out, and laid down with their upper ends supported a few inches above the floor, upon some old moulds laid for the purpose of facilitating the knocking off the hoops and taking out the ingots. This is done in a few minutes after they are cast, and they are then carried into the yard to cool.

When the coke put into the holes after the empty pots has been burned down, so as not to be higher than the pot-lids, a fresh charge of steel is put in, and the former process repeated a second and a third time. Attempts have been made to carry it to a fourth round; but this has been abandoned, the number of failing pots causing it to be attended with loss.

General Remarks.—The great extent to which cast-steel is now used in the arts, it was thought, would justify, if not demand, this minuteness of detail. The concluding observations will be more general. If soft and hard ingots of best-marks cast-steel are to be made the same day, the soft steel should be put in the first round only, for it requires the greatest heat and the most time, and should be done while the pots are in the best condition. For the same reason, if heavy and light ingots have to be made of the same steel as for saws, the heavy should be in the first round, and the light in the last.

Cast-steel may be made directly from the wrought-iron, without previously undergoing the process of converting; and when that is done, the bar-iron is cut cold into bits 1½ or 2 inches long by the large shears of a rolling mill. About 30 lbs. of these bits, with some charcoal, are put into each melting pot, the quantity of charcoal depending upon the use the steel is intended for. If it is for tools, about eight ounces will be a proper quantity. This method of making is preferred for some purposes, but is not adopted extensively, being rather more expensive than the usual method; for the cutting of the iron costs nearly as much as converting, and the melting requires more time, more coke, and costs more in other respects.

When larger ingots than one pot will contain are wanted—65lbs. or 70 lbs., for instance—moulds made to hold that quantity are prepared. Two pots are taken out, their lids taken off, and the steel of one pot poured to that of the other; then the pot containing the whole is poured into the mould. This being as great a weight as can be poured into the mould from one pot, when greater weights are wanted, say 120 lbs. or 130 lbs., four pots are taken out, and the steel of the four poured into two. Then two men take them, one standing on each side, and pour the steel into the mould, one man beginning to pour before the other has done—for if the stream be stopped the ingot will be spoiled; this it is which makes it so difficult to cast very large ingots by the English method. The men should be well drilled, so that each may know what he has to do and when to do it, before the attempt is made; but, notwithstanding the difficulty, a sound ingot requiring about sixty pots has been made in this way.

It is not many years since no ingots of cast-steel were made larger than could be drawn under the hammer of the shear-steel forge; but since ingots of several hundredweights each have been made for the piston-rods of marine-engines, crank-pins, and other purposes, forges have been erected specially for drawing them, with suitable furnaces for heating, and machinery for moving them. Some of the hammers are on the same principle, and lifted in the same manner as those of the ordinary iron forge; and Nasmyth's steam-hammer is also coming into use, the first of them having been some time at work at Sheaf Works.

About four tons of hard coke are required to make one ton of cast-steel.

Patented Processes.—A method of uniting cast-steel to iron was patented many years ago by Mr. Arnold Wild, which was ingenious, and might have been expected to become extensively useful, especially in those cases which require the union of large surfaces. Some difficulties attended it in practice, and have prevented its adoption for each and all the articles enumerated in his original design. It has been, however, and still is, occasionally used for some other purposes; and on that account a short description shall be given. An ingot mould is to be prepared as for cast-steel of such size and shape as the united piece of iron and steel is intended to produce. A piece of wrought-iron is to be forged so as to fill that part of the mould which is intended to be of wrought-iron, leaving room for that which is intended to be steel. The steel is now melted in the usual way; and when ready, the iron, heated to a welding heat, is to be put into the mould, and the fluid steel poured on it. The ingot or slab thus formed may afterwards be drawn by hammering or rolling to the size required. The practical difficulties are principally these two:—The surface of wrought-iron at a welding heat oxidizes so rapidly, that when the oxide is cleaned from it as well as it can be, just before it is put into the mould, another coat of oxide forms upon it before the steel can be poured in, which prevents in many cases the perfect union of the two; when that happens, the material is spoiled and of little value for any purpose whatever. The other difficulty lies in the great difference in the hardness of the two at the temperature proper for drawing cast-steel, which must not be exceeded, or the steel will be spoiled. The iron extends, by reason of this, so much faster than the steel, as far to overlap it, and occasions much waste of iron, for all that which extends beyond the steel is cut away as useless, and leaves the steel thicker than the proportion it was intended to bear to the iron; while, without that additional disproportion, the nature of the process requires more steel to be used than could be necessary or useful. Thus, success being doubtful, and when successful wasteful, Mr. Wild's method is little used. Hard and soft cast-steel in the same ingot can be made by a method somewhat analogous to that above described for uniting iron and steel, but much more practicable and useful, which was complimented by the award of a medal to Blake and Parkin at the Great Exhibition of 1851. This method is used with great success and advantage for making such articles as the knives of the patent paper-cutting machines; machine plane irons; the knives of tobacco-cutting machines; cork knives; and, in

general, for any description of large machine knives requiring a fine cutting edge of the best cast-steel, with a back of a softer and, without detriment to the utility of the article, cheaper material.

Suppose it is required to make an ingot, of which the hard cast-steel shall only cover a part of one side—that which is to form the cutting edge, as in paper machine-knives and machine plane-irons. A cross section of the mould will be of the shape represented in Fig. 11 for the soft steel; and a parallelogram for the mould in which the hard steel is to be united with it: this last should be slightly larger, both in breadth and thickness, than the other, so as to admit of the soft ingot being put into it without difficulty when hot. The soft steel ingot is cast first; and as soon as it has become solid it is taken out of its own mould and put into the other mould; and the space left, which is that included by the dotted lines, filled with hard cast-steel. When the hard steel is to be the whole breadth of the ingot, it will easily be seen that two moulds must be provided, the one for the soft steel a little narrower, and from one-half to two-thirds of the thickness of the union-mould. When the hard steel is to occupy the middle space between two sides of soft steel, the two moulds for the soft steel should not exceed in thickness one-third of the thickness of that in which they are to be united. Two of the soft ingots must be cast at the same time, taken out and placed in the union-mould, one on each side, and the hard steel poured in between them. Another useful application of this principle may be made to the casting of ingots for piston-rods of steam-engines. For this purpose a round or octagon ingot may be cast of about 2½ or 3 inches diameter of soft steel, taken out as soon as it is solidified and placed in the centre of another mould of the same form, of 4 or 4½ inches diameter, and the hard steel immediately poured in. It is scarcely necessary to say that steel may be made with a hard centre and soft externally, by reversing the last-named process. A man accustomed to this kind of work scarcely ever fails to make the two sorts of steel perfectly unite.

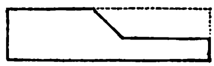


Fig. 11.

Heath's Patent.—It is to be observed that throughout this process the best Swedish iron, or iron of a similar compound, is required. The best Swedish iron, on analysis, presents the following results:—

Protoxide of iron	98·78
Carbon	·84
Silicon	·12
Arsenic	·02
Copper	·07
Manganese	.07
	99·90

From this analysis it will be apparent that manganese forms an ingredient in Swedish iron, while sulphur and phosphorus, usually in combination with them, are absent. Now this brings us to a point in the manufacture

of steel, alike disgraceful to the patent laws of this country and some of the steel manufacturers of Sheffield, who have availed themselves of the loopholes of the law to take advantage of the patentee. To tell this romance of steel with effect, we must have recourse to Mr. Dickens's "Household Words," where the story is told in a very graphic manner; premising, however, that we shall sometimes condense the information it contains, and sometimes quote from that work; and at others avail ourselves of other sources of information.

Not many years ago, a civil servant of the East India Company was requested by a friend to obtain for him, among other things, some steel heads for boar-spears. This request was made to Mr. Josiah Marshall Heath, while fulfilling his duties in the interior of India; and to comply with his friend's wishes, he was led to visit the Indian steel-works. He was much struck with the clumsiness pursued in the whole process—clumsiness not to be tolerated by a man naturally quick-witted. Mr. Heath was quick-witted enough; he had been carefully educated for the Company's civil service, and went to his post so well versed in Oriental literature, that a Sanscrit Professorship was offered to him before he had attained the age of twenty-one.

In executing his friend's commission, Mr. Heath came to the conclusion that Southern India possessed immense capabilities for carrying on the iron and steel manufacture; and from that time he prosecuted an energetic research. Haunted with this impression, he traversed the Malabar coast, where he discovered mountains of iron ore, and it became evident to him that India could supply England and Europe with the best and cheapest steel-iron; that ships at that time paying for rubbish to bring home as ballast, might be ballasted with Indian iron. The Indian ores were pronounced, however, by experienced metallurgists, to be unmanageable. Known processes could not convert them into marketable steel or iron; but Mr. Heath was not to be daunted. In 1833 he became the founder of the Indian Iron and Steel Company, and probably originated the investigations which are at this moment being carried on under official directions in that country. In order to carry out the mission with which he had charged himself, and confident of great results, Mr. Heath resigned his appointment, and devoted his private fortune and the pension granted him by the Company to traversing the entire western coast of India; visiting all the celebrated iron and steel works in the world, including those in Sweden; and acquiring, in these journeys, a familiar acquaintance with the processes of iron and steel manufacture; verifying old and prosecuting new experiments. After these elaborate and costly researches, he found himself at last in London, with his resources utterly exhausted, but with his object, as he conceived, perfectly attained.

In 1830 he took out a patent; and in the specification he briefly describes the nature of his invention, namely, "the use of carburet of manganese in any process for the conversion of *iron* into cast steel;" but it does not appear that any progress was made in its application till 1840, when Mr. Heath visited Sheffield for the purpose of introducing his invention among the steel manufacturers. This discovery is said to have changed the whole aspect of

the Sheffield steel trade; and largely increased the quantity of steel produced.

But it is to be borne in mind that the smaller amount of annual produce had gained for Sheffield her world-wide reputation; while, on the other hand, it does not admit of much doubt that Mr. Heath's invention has greatly contributed to destroy this well-earned fame, by the facilities it offers for making steel of an inferior material; while it has gained for her the opprobrium of this case, in which many respectable names must share: although the invention itself is said to be valueless to them. But let us proceed with the story as told by the writer in the "Household Words."

Up to the time when Mr. Heath visited Sheffield to introduce his invention, it had been known only as 'Heath's powder' at the steel works; but, on this occasion, he was induced to communicate to his agent that equally good results would arise from merely putting the ingredients,—namely, a small per-centage of oxide of manganese with a little coal-tar,—into the crucible in which the steel was to be fused; for the carburet being formed at a lower temperature than is required to melt the steel, the one process would prepare the way for the other. Mr. Heath thus placed in the hands of the agent, instead of the powdered carburet of manganese, which was secured to him by patent, the elements of which it was composed.

Intercourse between Mr. Heath and the Sheffield manufacturers was for a time interrupted. But one luckless day he discovered that his rights had been invaded. His agent had established steel works, and was engaged in making steel according to the patent process; and from that time to the present, steel has been constantly made in Sheffield according to Heath's patent process, while all claim to remuneration set up by the patentee has been utterly denied. Well may the writer in "Household Words" ask—How can that be? One point in litigation we have already indicated: it was whether Mr. Heath as a patentee was not bound to make his carburet of manganese outside the crucible of the steel manufacturer, and whether the modification he afterwards suggested might not be adopted by them without legal infringement of his patent rights—a most miserable quibble on the real merits of the case, if the only defence. But it is to be observed that, long before Mr. Heath's patent existed, the black oxide of manganese was used in connection with charcoal; and also with other substances, such as soda and borax, in making cast-steel. The patentee, we believe, regarded this use of the oxide as an infringement of his patent, because it was said to become carburet in the melting-pot, as stated above. But there could be no such infringement, since it was used in more than one manufactory previous to 1830; and in "Chaptal's Chemistry," a work published about 1815, the reader is told that eight parts of oxided manganese takes up by a gentle heat three parts of sulphur; and at page 292, vol. i., it is said that iron may be separated from manganese by the greater affinity sulphuric acid has for the manganese. This led, in one instance at least, to experiments with small quantities of manganese in making cast-steel before Mr. Heath's process was known.

The case—which is one of the many which bring disgrace on the English

Patent Laws—has been dragged in a circle round a series of courts. In the first instance it was tried before Lord Arbinger in Trinity Term 1843, when the plaintiff was non-suited. It was again tried in June, 1844, in the Court of Exchequer, when many delusive pleadings were raised; but finally a verdict was found for Heath on all the issues.

This verdict, strange as it may seem, was, after three years' consideration, set aside, and a new action raised in the Court of Common Pleas, under orders of the Court of Chancery, which was at last tried in November, 1850, before Mr. Justice Cresswell. That learned judge, "mindful of the etiquette of the bench, declared that he could not, sitting singly, confirm or reverse the judgment of the Court of Exchequer; but that he would direct the jury to find for the defendant, and the plaintiff would then be at liberty to bring the whole case again before a competent tribunal."

Will the result of this tortuous course of litigation surprise the reader? asks Mr. Dickens. "Mr. Heath procured a stall at the Great Exhibition of 1851—arranged with his own hand his rare metallurgic specimens; but before the Exhibition opened, and before his case came again to be argued, his weary heart ceased beating. He died! leaving his successors to prosecute the claims they derive from him."

How far this invention has been beneficial to the steel manufacturers may be considered somewhat problematical. That it has largely increased the trade of Sheffield may be true: that it has exhibited a grievous absence of honourable dealing on the part, it is said, of some seventy or eighty men holding the position of manufacturers there, may be equally so. But the men who are most interested in upholding the character of Sheffield steel assert, that it only enables the inferior manufacturer to substitute inferior articles—knives and axes that will not cut, and blades on which no reliance can be placed—in place of the cast-steel produced from Swedish iron, and others having the same characteristics; and who further assert that no mode has yet been discovered of converting into good steel the common iron of this country, produced by the ordinary processes in use.

It is even known, moreover, that Mr. Heath was not very successful in his own experiments; for he had a furnace built at the Fitzalan Works under his own directions, for the purpose of granulating the iron by melting and letting it fall into water; much as is done by Mr. Bessemer, Capt. Uchatius, and some other patentees of our own day. But the steel made by him was, when his own plan was followed, in every respect so unsatisfactory, as to lead to the abandonment of the plan.

Bessemer's Patent.—The improvements claimed are, firstly, in preparing the iron for its conversion into steel; for which purpose, bar, plate, hoop, or scrap iron, is put between a pair of "slitting rolls," whereby they are cut into narrow strips, which are afterwards put crosswise through the same rolls, so as to cut the metal into small pieces; a revolving cutter or other suitable shearing machine may also be used. In other cases, granulated puddled iron is used in lieu of the small pieces of bar, plate, hoop, or scrap iron; the metal so granulated or cut will then be in a condition suitable for its conversion.

into steel by the process of cementation with charcoal or other carbonaceous substances in close retorts, tubes, or chambers, placed in a vertical position, so as to admit of the iron and charcoal falling through by the force of gravity whenever the lower portion of the vertical column of materials is removed. The upper and lower parts of the retorts are to be kept cool, by placing them in a tank of water or by exposing their outer surfaces to the atmosphere, while the central portion is exposed to a red heat in a suitable furnace or oven. The parts of the chamber exposed to the action of the fire should be constructed of fire-clay, while the top and bottom ends of the retorts, tubes, or chambers, may be made of iron, to facilitate their cooling. The lower ends of the retorts, tubes, or chambers are provided with sliders or stop-pieces below the tubes, for the discharge of a portion of the materials from time to time. When a portion of the charge of materials is thus allowed to escape from the lower ends of the retorts, a fresh portion should be admitted into the upper end, and thus the process rendered continuous after the process of cementation. The charcoal may be separated from the converted iron by allowing the mixed materials to fall into water, from the surface of which the charcoal may be removed. The metal so treated is to be smelted in close pots or vessels, from which the atmosphere and vapours of the furnace are excluded during the melting process. When puddled, scrap, or other iron has been converted into steel by cementation in upright retorts, or by any other means, or when iron has been partially deprived of its carbon by puddling, or when iron bars are converted into blister-steel by cementation, it is melted in order that the crude-steel may be cast into ingots for the purpose of being rolled or tilted into sheets, bars, or rods, or in order that the molten steel may be run into moulds for the production of various articles in cast-steel by the founding process; for this purpose a furnace is constructed, divided into a number of compartments or chambers, each one having a separate fire-grate and flue, so that each compartment may be worked independently of the other. This furnace is of a circular form, having a large cone rising from its centre, around which the separate compartments are arranged; the mouth of each one is on a level, or nearly so, with the floor of the foundry, and below ground is a large "cave," into which the ash-pits of the several fire-grates open, and by means of which the workmen get access to the under side of the fire-grates; the cave serves as a means of supplying air to the furnace, the air descending through gratings in the foundry floor. The central cone is so constructed that separate flues for each compartment of the furnace are formed in the thickness of its walls: the central part is open at the top to the air, and the space within the cone at its base forms the casting-pit, in which the moulds are placed; access is had to the casting-pit through an arched opening on one side of the cone. Into each compartment of the furnace a fire-clay or black-lead melting-pot is placed, raised above the fire-bars on a hollow fire-clay support; the pots have a tapping-hole in the lower part, which may be stopped up with damp sand, loam, or luting—having access to it through the hollow support of the pot from the under side of the fire-bars; the tapping-hole is placed vertically, but when placed in a horizon-

tal direction, the tapping-hole is opened by introducing a rod through a hole made in the front of the furnace for that purpose. The upper part of the pot has a dome, having a central hole for the plug to pass through, and one or more feeding-holes, with suitable plugs to close them air-tight.

The cover should be mounted on wheels, and have a rim or flange fitting so close to the top of the furnace as to exclude the air as far as possible, or a sand-joint may be formed. At the back of the ash-pit of each compartment there is an opening in the wall of the cone, through which at the time of casting an iron gutter is placed, lined with loam, one end of each gutter being placed below the tap-hole of one of the melting-pots, while the other end of the gutters communicate with the gate of the mould, so that on a signal being given, the workmen simultaneously open the tapping-holes of all the melting-pots: the contents may thus be rapidly accumulated in a single casting when required. When small castings are required, the tap-hole should be stopped with a long fire-clay plug, which may be used as a valve to let out as much metal as is required at a time, the plug keeping the tap-hole shut until another mould is ready. In order to obtain the intense heat requisite to melt steel, good hard coke may be placed all around the melting-pot, and also over the top of it, so that it may be completely enveloped in the burning fuel. When a mixture of iron is put with the steel, the iron is put at the top of the charge of steel, so that when it melts it may run down and fill the interstices between the pieces of steel, and assist in their fusion.

In order that the invention may be carried out with economy in situations where coke is more expensive than coal as a fuel, the following alterations in the form of the melting-vessels and furnace, which will admit of the use of coal in its raw state, is used: the retorts are made with closed tops, to exclude the atmosphere and gases of the furnace, and provided, in like manner, with tapping-holes for the discharge of the fluid metal.

For this purpose a furnace is constructed similar in form to the common reverberatory furnace; the part behind the fore-bridge being occupied with fire-clay retorts, placed crosswise of the furnace, and supported at different parts, so as to form a series of flues beneath them, while the flame is allowed to pass over and envelop them as much as possible. The retorts have closed ends and tops, with the exception of a feeding or charging hole near the upper part, and a small tapping-hole near the bottom, which is to be plugged with loam, damp sand, or a plug of fire-clay, during the melting of the materials, after which the tapping-holes are opened, and the contents of the melting-vessels may be run into a ladle or direct into the mould; or the after-part of the furnace may be so formed as to melt down the iron, or receive a charge of melted iron from another furnace; and the steel may, in that case, be melted alone, and be afterwards tapped out and allowed to flow into the fluid iron in the after-part of the furnace, from which the whole may be run into moulds, whereby cast-steel articles, or articles of a mixture of steel and iron, may be produced.

In a subsequent specification Mr. Bessemer professes to make steel of a superior quality by following up his process for refining crude-iron by the

process already described in a former chapter. The modified process by which it is proposed to prepare the iron for conversion into steel of a superior quality, is as follows: He proceeds, in the first place, to refine the crude iron, carrying on the process until the most complete refinement has been effected, and the iron is as nearly pure as may be; he then pours the fluid iron into water, by which it becomes granulated, and the grains or shot so produced are afterwards converted into steel by the process of cementation with charcoal in the upright retorts, already described. The blister-steel so produced is melted in crucibles, as at present generally practised in the manufacture of cast-steel, or by any other suitable means.

Uchatius's Process.—In this process the pig-iron is granulated by pouring it while in a molten state into water, and it is then in the best state for conversion into cast-steel. To the pig-iron thus reduced, pulverized sparry iron and fine clay are added; or gray oxide of manganese may be used instead of the latter. This mixture is put into crucibles, and the process of melting and casting is proceeded with in the usual way for producing cast-steel. In order to obtain the harder kinds of steel, charcoal may be added in small quantities to the above-mentioned combinations. In the words of the specification of the patents, this process is founded on the assumption, that cast-iron, enwrapped or surrounded by any oxygenized materials, and subjected to a cementing heat for a given time, will yield up a portion of its carbon, which will combine with the oxygen driven off from the surrounding materials, and form carbonic oxide or carbonic acid gas. If the operation is interrupted before the completion of the process, a partially decarbonized iron will result, the surface of which will have been converted into a pure iron, while the interior parts remain unchanged; or, in other words, the progress of the decarbonizing action will depend on the amount of metallic surface brought into contact with the oxygen-yielding material with which the iron is surrounded. In order to expedite the operation, the pig-iron is reduced to a granulated state; and to economize fuel and labour, the heat required for effecting the decarbonization of the iron is used to reduce the metal, when sufficiently decarbonized, to a molten state, and thus by one and the same heating to convert it into cast-steel, which only needs to be forged to prepare it for the market. The granulated iron is mixed with about twenty per cent. of roasted pulverized sparry iron ore and four per cent. of fire-clay; the mixture is placed in fire-clay crucibles, and subjected to the heat of a cast-steel blast-furnace of an ordinary construction. By thus subjecting the granules of iron in presence of the sparry iron ore to a melting heat, the enwrapping oxides will first effect a partial decarbonization of the granulated iron, which decarbonization will be limited in amount according to the size of the granules operated upon; and by reason of the continued application of heat, the iron will, with the assistance of residues of the sparry iron ore, melt and separate from the impurities with which it was mixed, and bring down with it a portion of the iron contained in the sparry iron ore, thereby increasing the yield of cast-steel by about six per cent.

The quality of the steel is capable of being by this process considerably

modified. Thus, the finer the pig-iron is granulated, the softer will be the steel made therefrom. The softer sorts of welding cast-steel may be obtained by an addition of good wrought-iron in small pieces, and the harder qualities by adding charcoal in various proportions to the before-mentioned mixture.

It would be foreign to our purpose even to name all the processes patented for this interesting manufacture; even to do so would, indeed, more than fill the space we can devote to the subject. We, therefore, content ourselves with what may be considered the more prominent patent processes.

Natural Steel.—The principal countries whence the so-called natural steel is obtained, are situated in the vicinity of very pure and easily fused iron ores; in the Central Alps, Styria, Carinthia; on the Sieg, the Moselle, and the Soane; and in the neighbourhood of the Stahlberg at Müsen, and in the Thuringian forests; as these can only be profitably worked where charcoal fuel is easily obtained, the production is limited by the resources of the neighbouring forests. Besides the processes we are about to describe, by which, from the excellence of the ores, steel is obtained by merely remelting the pig-iron, steel is also obtained in various parts of Germany by a puddling process. Since 1850, however, converting-furnaces, on the most improved principles, have been constructed both in France and Germany; and the best judges bear testimony to an immense improvement in the steel implements manufactured in these countries since the Great Exhibition year.

The various methods for refining raw steel in Germany depend upon the nature of the iron to be operated upon; they are described as follows by Dr. Bruno Kerll, to whom we are indebted for the facts herein stated.

1. Gray raw-smelted cast-iron, of a light liquid, occurs in Westphalia, Silesia, Konigshütte, in the Hartz Mountains, in North Germany, and in Sweden.

2. White rough smelted cast-iron (specular iron) occurs in Siegen, in Western Germany, in Sweden, and is used in some French foundries. This iron differs slightly from the former, so far as is required for the treatment of specular iron.

3. White refined cast-iron, which has been freed from a portion of its carbon in its preliminary treatment. This occurs in Styria, Carinthia, and the Tyrol—at least in Northern Styria and a portion of the Tyrol.

According to the South German method, the iron is first prepared in distinct furnaces, then remelted and cast into ingots or pigs; while in North Germany the smelting and converting process takes place in the same furnace, and answers to the preliminary preparation of the Styrian method. The metal thus prepared is refined into ingots, and a considerable gain in time and fuel results. All these methods produce the same results where the iron is of a similar quality; and the higher reputation in which the South German method stands, is chiefly owing to the superior quality of the material.

In the working of gray rough-smelted cast-iron of a slightly fluid character, the pigs of cast-iron are fresh warmed at the mouth of the furnace, then gradually melted down with iron slag, the blast used being very deep and rapid, and the fuel suffered to burn hollow. When the iron is precipitated in a

molten form, the blast is gradually reduced, and the iron stirred up for some time with more slag, until it becomes rather stiff. In this manner various lumps of cast-iron are smelted down. The blast is now set to work with great rapidity, and the iron is stirred round, becoming more fluid with the increased heat. If the steel be allowed to run from the slag-hole at the period when it becomes fluid at the surface, the result is the so-termed wild-steel, which, while excessively hard, possesses no malleability or capacity for welding, and is never sought after for the wire-drawers. If the mass has so far progressed that the cakes settling on the bottom can no longer be pierced by the poker, additional lumps of cast-iron are thrown in as described above, and again stirred up. On smelting a new pig, the mass contained in the furnace is again reduced to a liquid state, in order that the steel may be a thoroughly homogeneous mixture. The great object is to interrupt the process at the exact moment when the mass begins to harden, and scales attach themselves to the crowbar. The blast is then removed, the fuel is thrust back, the lumps are taken out, brought under the forge-hammer, broken into several pieces, and welded, while the smelting process is still going on with other ingots.

This treatment is principally employed in Westphalia and Silesia for gray cast-iron, but is also applied to the white iron at the Königshütte in the Hartz. In Westphalia and Upper Silesia, 1 cwt. of raw steel requires 40 Prussian cubic feet of coals. In ordinary cast-iron, 3 cwt. generally give 2 cwt. of steel; better sorts give 5 cwt. from 7 cwt. of cast-iron; and in our very best varieties, 4 cwt. of raw iron give 3 cwt. of raw steel. The weekly production of a furnace will amount to about 25 cwt. At Königshütte, 100 lbs. of white cast-iron give 76·63 lbs. of raw steel; and 100 lbs. of raw steel require 28·1 cubic feet of coals. From 2 to 2½ cwts. of raw iron are smelted on each firing. In the Mark, old welding-iron is added, by which the refining process is assisted; but the result is an absence of that homogeneous mixture required in the best steel. In Styria, the gray raw iron is brought to a white heat in a peculiar closed furnace, and is then suffered to run off in a molten state through a tap.

The conversion of specular iron into steel is also effected in Siegen, and the process only differs from the North German method in consequence of the specular iron being rendered fluid at a lower degree of heat, and thickening more rapidly than the other ores. The steel produced from it is also more homogeneous. The welded bars are thrown, while still at a red heat, into running water, being thus hardened and afterwards broken into thin bars, by which two sorts of steel are obtained—namely, 75 to 76 per cent. of hard, brittle steel, and 24 to 25 per cent. of a softer and less brittle quality. 100 lbs. of raw steel consume about 17 cubic feet of coals; and one fire produces weekly from 40 to 50 cwt. of steel.

Two methods may be distinguished in working white refined cast-iron containing a smaller proportion of carbon. In the Styrian steel-forging process employed in Northern Styria, at St. Gallen, and in a portion of the Tyrol; blooms which do not contain too much carbon are placed, without

any preliminary working, at a considerable height above the mould in a forge, and smelted down, with a blast either high or low, according to the nature of the iron.

The Carinthian or Brescian steel forging process is distinguished from the Styrian method, by the smelted cast-iron being torn into pieces in the furnace, these being then roasted by the usual process, and then worked up into steel. Through these preliminary processes, which entail an increased expense in firing, a better article is produced, which is not generally refined, but merely heated and drawn out by the hammer.

The Carinthian method is employed, with a few modifications, in the Paal (in Styria); whence the Brescian forging is divided into the Carinthian proper and the Paal system. Both have the process in common, the proportion of unprepared iron being larger in the Paal than in the Carinthian method; and in the same process, the ingots, which are employed to refine the cast-iron, possess a higher grade of refinement. Furthermore, in the Paal method, all the ingots, prior to welding, are dipped into raw iron in a liquid state in the furnace; and, by remaining in it, the steel gains both in hardness and firmness. By the Paal-Brescian process, various sorts of steel are obtained, which are distinguished according to their quality and mould.

Puddled Steel.—The German steel manufacturers employ the puddling process for rendering their product available for many purposes. This process has this advantage over the steel smelted direct from the ore or from pig-iron, that, by a slightly modified manipulation, harder or softer steel can be obtained. When a fine hard quality of steel is required, smelted and cemented steel must be employed, the puddled-steel being only suited to fill the gap which exists between smelted-steel and puddled bar-iron.

In steel puddling, the whole mass of smelted iron is brought into contact with the oxygen by repeatedly stirring, as in iron puddling; so that at last the smelted portions are capable of being welded. As soon as the iron is in a liquid state, it begins to rise, and refined ingots are formed; the forge-plate and puddling-holes are closed, by which the remaining iron is precipitated to the hearth, where it is covered by the still raw slag. The decrease of temperature, consequent on excluding the air, soon produces such a considerable degree of consistency in the mass of metal, that the workman is able to form it into the required balls, and bring it under the hammer, where it is hammered into the required shape. The ingot thus formed is again heated, and brought to the proper form under the rollers. In these operations, the deoxidizing effects of the atmosphere on the metal are to be avoided as much as possible.

For the production of good steel, the slag, after the stirring is completed, should be in such a state of combination, that, with a proper degree of fluidity, its decarbonizing effect is reduced to a minimum. By the employment of specular iron, which melts easily to a fluid state, the metal retains its heat in the furnace to the end of the process, while the addition of cold raw slag restores it to the proper refining temperature. Less dependent for success on the condition of the added slag is the steel-puddling process for work-

ing up honeycombed iron, which contains a slight proportion of manganese and carbon.

The ingots produced in the puddling-furnace are either refined by faggoting, as before described, or heated to a welding point, and rolled or hammered to the proper dimensions.

The German steel-puddling furnaces differ from the bar-iron puddling-furnaces in having a rather smaller and deeper hearth, a tighter closing chimney, fewer additions of raw iron, and coarser slag fluxes. For the better preservation of the side-walls of the puddling-stove, the iron walls are provided with a thick water circulation (as at Geisweide in Siegen), or with a strong ventilating machine (as at Haspe in Westphalia); and the sole-plates are two to three inches thick, for the purpose of quicker cooling.

In steel-puddling, the duration of the charge is somewhat shorter than in iron-puddling; but through the slight addition of slag, the repeated repairs of the ground, the more costly fluxes, &c., the production of steel-ingots is generally more expensive than that of forged iron pigs. In steel-puddling, the main point is that the work may go on as regularly as possible from beginning to end, that, therefore, the smelting and refining may follow regularly, and that the refined mass may be removed from the furnace as speedily as possible. For this purpose, great care must be taken not to add different qualities of iron, which behave differently in smelting and refining; for instance, the fluid specular iron and gray iron should never be mixed up with the white honeycombed iron, which assume a pasty condition in the furnace. By the addition of such different qualities of metal, one portion of the iron would be undergoing the refining process, while the remaining more carbonized and fluid portion still remains in a liquid form in the furnace.

The object of steel-puddling being only to consume a portion of the carbon contained in the raw iron, is principally facilitated by the exclusion of air at the moment when the still remaining carbon is sufficient for the production of steel. In Germany, puddled-steel is not employed so much in sharp weapons, blades, hard instruments, files, pins, and saws, as in the rolled out state for steel ornaments and fancy articles for common cast-steel, for steel axles, winches, tires, &c.

Damaskeened Steel.—By damaskeened steel is meant that sort of steel which receives shades of a darker and lighter colour after the surface has been corroded with acids: it is remarkable when genuine for its elasticity and strength, and for its homogeneous fracture when broken. We distinguish—

1. Natural Damascus steel, which comes from India and Persia, and which is distinguished by its excellent quality and mixed veining, and is worked up principally into sword-blades. These Oriental blades consist of a more highly carburetted steel than any European manufacture seems to possess, and in which, by skilful cooling, a division of two different carburets has taken place. This separation is clearly visible on corrosion with acids, as the parts exposed to the action of the acid are deepened and dyed by the exposure of the carbon, and with the other less affected, and consequently

brighter parts, produce a design, more or less delicate, of gray and white lines, which often have a certain degree of regularity. A distinction is made between parallel striping or waving lines, and mosaic damaskeening.

If the cast-steel is made in iron moulds, as usual, the above separations do not take place. By re-welding and sudden cooling, the Damascus steel loses its pattern. The Indian Woolz, as especially used for sword-blades, contains foreign substances mixed with it—as nickel, tungstate of iron, or manganese—which are said to impart the peculiar value to it.

Few European smiths have succeeded in working up Indian steel, because they do not accurately know the temperature required for its treatment. In consequence of the large amount of carbon it contains, 7·18 per cent., this can only be effected within certain climatic limits: if too high a temperature is exhibited, it breaks to pieces under the hammer; if too low, it assumes a hard and brittle character. The iron appears disposed to receive a considerable quantity of carbon, through the manganese combination.

2. Artificial damaskeened steel. Attempts have been made, with more or less success, to imitate the real damaskeening, and the following methods have been suggested:—

Luynes entirely imitated the Indian process; smelting soft iron with charcoal, tungstate of iron, nickel and manganese, was highly successful. The manganese, more especially, produced damaskeened steel, and introduced a large quantity of carbon, without injuring its malleability.

Bréant produces a most valuable damask, very closely resembling the real, by smelting one hundred parts of iron with two parts of lamp-black, or by smelting cast-iron with oxidized iron-filings.

Clouet, Hachette, and Mille, smelt iron plates of different natures, harder and softer, together, and produce a damask remarkable for its elasticity and hardness, but not having the wavy damaskeening of the real blades.

CHAPTER XVIII.

THE APPLICATION OF STEEL TO VARIOUS PURPOSES, AND THE METHOD OF HARDENING AND TEMPERING APPLICABLE TO EACH.

There are few things of which it is more difficult to understand the *rationale* than hardening steel; or why the same operation, of heating red-hot and plunging into a cold fluid, which hardens steel, should soften copper.

Some persons will explain everything, whether they understand it or not, and for this also have they found, in their own imaginations, a perfectly satisfactory answer, and cut the difficulty by saying steel is condensed by the operation; but, unfortunately for their theory, the reverse is the fact; and instead of being condensed, it is expanded by hardening, as any one may soon satisfy himself by taking a piece of steel as it leaves the forge or anvil, and fitting it exactly into a gauge, or between two fixed points, and then hardening it; it will then be found that the steel will not now go into the gauge or between the fixed points. Or let him rivet together a piece of steel to a piece of iron, filing the ends of both even, so that they may be exactly the same length; then heat them to a proper heat to harden the steel, and plunge them into water, he will find the expansive force of the steel has nearly torn the rivets out, and that it extends beyond the iron at both ends. Any article may be taken with steel on one surface and iron on the other—such as a joiner's plane-iron in the forged state—flat on both surfaces, and hardened; and the expansion of the steel will cause that side to be convex, and the iron side concave: how this is got flat again will be explained afterwards.

All steel expands in hardening; but that the most which is most highly converted, and in direct proportion to the amount of carbon it received in that process. No other general rule can be given for the heating of steel for hardening than this; that it should in all cases be heated as regularly as possible to the lowest temperature at which that particular kind of steel will harden, and as little as possible beyond it, remembering that the more highly converted the steel is, the lower the temperature at which it will harden; and that a small article, such as a penknife-blade, will harden at a lower temperature than a more bulky one made of the same steel, because the small article is more suddenly cooled. The hardening of very bulky articles, such as the face of an anvil, cannot be effected in the same way as smaller articles, by plunging them into water; for the length of time required in cooling will be almost certain to leave the middle of the face soft, where it is of the most consequence that it should be hard. Where the anvil-forge is worked by water-power, they possess the best means of hardening them, which is this. The anvil, properly heated, should be placed in a water-tank face upwards, under a shuttle connected with the mill-dam; the shuttle drawn, and a

heavy and continuous stream of water let fall from a height of ten or twelve feet upon the anvil-face, which effectually hardens the surface.

A red-hot anvil plunged into water, would, for a time, be surrounded by an atmosphere of steam, which would prevent its direct contact with the cold water, whereby its cooling would be retarded too much to harden the face; and hence the advantage of a continuous stream of cold water. Hence also the necessity of moving about in the water even articles of a pound or two in weight, to remove them away from the steam as it is generated upon their surfaces, and thus promote more rapid cooling.

It is a good plan to harden hammer-faces, where there is a tub and water-tap conveniently near, by plunging the red-hot hammer, held with the face upwards, into the water, so that a stream from the tap may fall upon its face. The face of hammers and anvils is ground after being hardened, but should never be tempered.

A very large quantity of steel is used for file-making; and, within the memory of persons now living, great changes have been made in the trade by the application of different kinds of steel, and also in the mode of preparing it for the purpose. It is only about eighty years since large files were made from the blister-bars, without previous tilting or rolling. At that time the men used to slit the bars with a set into two, three, or four, according to the size of the bars and the files to be made: they were paid for the making by what was called day-work, for at that time it actually required a day to make the quantity known by the designation 4½ dozen of 10 inches, 4 dozen 11 inches, 3 dozen 12 inches, 2 dozen of 13 or 14 inches, 1½ dozen 15 inches, 1 dozen 16 inches, were a day-work; but all were not paid the same price for making. The file-forgers continued to be paid by the quantities above mentioned long after tilting-hammers, by drawing the bars to the sizes required, had so facilitated the work, that three or four times the quantity could be forged in a day that was made formerly. At the commencement of this century, and for about twenty years afterwards, the materials used by the best makers for double-hand work—that is, for files ten inches and upwards—was second marks blister-steel, such as GF, gridiron, Steinbuck, S and dots, for boss work, by which is meant such kinds as require a swage or boss to form them as half-round and three-square files; flat work was made principally of CCND, S and dots, and Steinbuck. The smaller kinds only and saw-files were made of cast-steel at the ordinary list prices; when large-sized cast-steel files were required, they were charged one-third more than the common steel prices. But it must not be supposed that the cast-steel then used, for which this extra price was charged, was the same in quality as that now in common use by the file-makers; it was very superior to it, being made of the best and second marks only. At the period referred to, rolled steel had scarcely come into use at all for file-making, the makers being of opinion that steel drawn under the tilt-hammer was much better adapted: they therefore had the steel for half-round, drawn the same as for flat files, and afterwards brought into the half-round form in bosses (more generally known in other places by the name of swages). Three-square or triangular files were made of square steel, by

putting one angle downwards in a triangular swage, or, more properly, one forming an angle of 120°, and hammering upon the upper angle of the steel, while the proper form was nearly attained, then placing each angle downward in turn, and hammering upon the upper side until all the angles were brought sharp up, and the equilateral triangular shape attained. Round files also were made of square steel, the points being drawn square as for square files; the angles were then knocked down, thus making the steel octangular. If this were well and regularly done, the round file was nearly made; but any fault up to this point could not be well repaired after the hammer had gone down the angles to make it sixteen-sided; in this state it was left for the grinder to do the rest, as no swages were used by the forger.

Triangular rolled steel began to be used for large three-square files about the year 1824; and the immediate cause of the change was this:—About that time lace-making machines began to be made extensively at Nottingham, for which three-square files, from fourteen to sixteen inches, were required, similar to the thirteen inch files, which had long been used in making stocking-frames. Making these large three-square files was unpopular with the men: the labour was much greater, they were less productive to the workman than common work; and the unusual demand coming at a time when other work was abundant, the demand could not be met. Rolls were, therefore, turned for this particular work for the first time. The lower roll has grooves turned in it, forming two sides of an equilateral triangle; and the third side is made by the plain roll which works over it. This altogether altered file-making.

Steel prepared in this manner made the thickest part of the file, which had been the hardest work, into the easiest. The men soon refused to work anything but three-square steel. Smaller sizes were then introduced, and are now used universally for all but small sizes of saw-files; and when square steel is used for them, an extra price must be given to the forger. Steel began to be rolled about the same time for half-round files. The first rolls were made to form the steel, so that a cross section of it would be bounded by two arcs of circles of different radius (Fig. 12); for it was thought that if the steel were rolled quite flat upon one side, a point could not be drawn without the edges of the steel being doubled over to the flat side; but it was soon found to be easy to prevent this, by placing that part of the steel which is to be drawn to a point, with the flat side downward, in the half-round boss or swage, and giving it a blow or two with the hand-hammer to turn the edges towards the back. The steel is now rolled to the segment of a circle (Fig. 13), produced at the rolling-mill by turning grooves the width and depth required in the lower roll, with a plain roll over. Steel for round files is now rolled round, and a very large proportion of the steel for flat files is rolled also. The reason of the preference formerly given to tilted over rolled steel was, that tilted steel appeared much finer and closer grained when broken than that which was rolled; and this difference is more

Fig. 12.

Fig. 13.

especially manifest when blister-steel is the subject of the comparison. But the objection against rolling of the greatest weight lay in the manner of heating at rolling-mills, where three, four, or five hundredweight of steel would be put into the fire at once, and the whole heated to the working heat before the rolling of it would commence, so that the last of it would lie in the fire, perhaps, half-an-hour at a higher temperature than such steel ought ever to receive before it was rolled, to the great injury of its quality: while in a tilt, though one or two hundredweight of bars may be put into what is called the smoke-hole, they can there only be heated to a low red-heat; whence they are taken one by one, heated quickly in the blast of the hollow fire to the working temperature, and tilted within one minute of their becoming hot enough.

But, it may be justly said, rolling must have some advantages over tilting, or rolled-steel would not be used where tilted would answer the purpose. The advantages of rolling are these:—Rods of steel can be made more exactly of the same breadth and thickness, from end to end, by rolling than is attainable by tilting. They can also be rolled of greater length than they can be tilted; and, since ends too short to make a file of the size the steel was intended for are never drawn down by the workman to a file of a less size, nor are two ends welded together, as was the case formerly, it is an advantage to have as few ends of bars as possible. The third and last advantage of rolling is, that it is about 20 per cent. cheaper than tilting.

Half-a-century ago, the greatest customers of the file-makers were the ironmongers, and their customers the smiths, who, when a file was worn out, could use it to steel horse-shoes, a plough-share, or an axe, or to make a chisel or some other tool; and in some such way most of the old files got used up, without being seen or coming into the hands of the file-maker again. But as mechanical invention and the use of machines greatly increased, the millwright, engineering, and machine-making establishments became the great consumers of files and of tools made of steel; and not having the same use for the old files, and worn-out tools, as the smiths, the engineers sell them as scrap-steel, to be worked over again by the persons of whom the files and steel were purchased at first. The increase of such old steel began to be very manifest, about the time that commoner and lower-priced Swedish irons, at £8 or £10 per ton, began to be introduced, which was about 1823; and the readiest way which presented itself of using up this scrap-steel was to make common cast-steel of it, by melting it with hard converted common Swedish blister-steel, and so making it into files again. In this way the files would cost little more (the advantage of having fewer wasters taken into account) than those made of the higher qualities of blister-steel, the difference in the cost of the material being nearly sufficient to pay the cost of the melting.

The same causes continue to operate, so that the actual quantity of cast-steel files has been greatly on the increase of late years; and scarcely any other kind is supplied to engineers, machine-makers, and iron-founders, or for the American and Continental markets, than this scrap-steel yields.

It is not intended to enter further into a description of file-making, than may be necessary for the purpose of understanding what are the different sorts of steel used, and the proper treatment of them. Blister-steel will bear a greater heat when forged than cast-steel, without injury. When files, after being forged, are heated red-hot, and cooled slowly to anneal them, so that they may be soft enough to be cut, care should be taken that they are never made too hot, nor continued at the full heat for any length of time after they have arrived at it, for that is almost as injurious to the steel. The latter is the danger most to be dreaded when the files are annealed in close vessels, which some recommend to prevent oxidation; for the files being out of the view of the person in charge of the furnace, he is not so able to judge when he ought to stop the heating, as when the files can be seen by him when he wishes, which he can do in the furnaces as they are usually constructed. Where this operation is as carefully conducted as it ought to be, the loss by oxidation will be very trifling. It would be tedious and unnecessary to detail the various ways employed; the object should be to heat the steel to a low red-heat, and cool it as slowly as possible. Omitting the grinding and cutting of files, we come to the hardening. The first thing to be done is to protect the teeth, so that they will not be oxidized when heated; this is done by covering them with something which will fuse at a red-heat, and form a sort of varnish upon the surface of the file, without acting chemically upon the steel, and which can easily be removed when it has answered its purpose. A substance answering to all these conditions is found in common salt (hydrochloride of soda); but to make it adhere in the first instance, something must be used with which it will form a kind of thin paste. A paste of flour and water will answer well; but the usual substance is ale-grounds, obtained from the brewers, or from the public-houses where they brew. Files are dipped in a mixture of these ale-grounds and salt, and the superfluous quantity removed by the finger and thumb, or with a brush; then heated in a hearth-fire with soft coke made by burning a soft bituminous coal, not in ovens, but on the surface of the ground; and, to save repetition, it may be here stated, that this is the kind of coke universally used in hearth-fires, for manufacturing purposes, in Sheffield. When the file is red-hot, it is set straight upon two lead-rests set upon a block—one of the rests being movable, so that it can be placed nearer or farther from the other as required; upon these the file, held by the tang in a pair of tongs, is placed as upon an anvil, if it be a flat three-square, round three-square, or square file, and is made straight with a hammer, also of lead; but if a half-round file, it must have such a degree of curvature given to it as experience has shown to be necessary, that it may be expected to come straight out of the water.

Now if we refer back to what was said of the expansion of steel in hardening; and to the process of conversion of bar-steel, by which it was shown that bars are always a little harder on the outside than in the middle, and may be a good deal harder if the conversion is hurried; and also that one side of a bar may be more converted than the other side of the same bar; we shall see abundant reason to expect, that, in bar-steel files especially, this irregu-

larity in the degree of carbonization will produce corresponding degrees of irregularity in the expansion of files in hardening, and be prepared to witness its manifestation in practice. This manifestation will be that when a bar, which was more converted on one side than the other, is made into files, the side most highly converted will expand more than the other in hardening; and the effect of that will be that the files will be crooked when taken out of the water—the hardest side will be full and the other hollow, causing what are known by the name of water-cracks. The file, carefully and equally heated to the proper temperature, held by the tang with tongs, is now dipped into a saturated solution of salt and water, contained in a large cistern; and as soon as steam ceases to be generated upon the surface by its heat, which is known by the noise ceasing which is made by it, the file is taken out, and, if it be a large one, there is generally so much heat in it as to cause the water upon its thickest part to boil: in this state it may be sprung a little, and will retain the position thus given to it when cold. The manner of doing it is this:—The hardener has a small, strong, rectangular, wood-cistern, half full of salt-water, standing beside the other, across the top of which there is a strong bar of iron fixed, and another of the same, movable nearer to or farther from the fixed bar. As soon as the file is taken out of the water, the man, laying down the tongs, takes the file by the point and tang in his hands and looks down it; and as in ninety-nine cases out of one hundred it will be found to have run a little crooked in the water, he puts the point or tang end of the file, as the case may be, under the fixed bar of the small cistern, and using the movable bar as a fulcrum, presses upon the other end of the file with one hand, while with the other he puts water upon it; looking at the file again and again, and using the same means to bring it straight until it is nearly cold, after which no further effect can be produced upon it.

Nothing but experience can teach a man the amount of pressure which is necessary, and may be safely employed without breaking the file. The same method is taken with all descriptions, whatever the kind of steel they are made of, to obtain straight files; but the prevention of water-cracks must begin at an earlier stage. The blister-steel to be used for files should be thoroughly converted, and be broken, by some careful person well instructed in the qualities and properties of the different marks, into such lengths as are suitable, when rolled or tilted, to make a bar of the required size. If he finds any too highly carbonized to be safely used, he should lay it aside to be remelted; if too hard to be safely used, say for sixteen-inch files, it may be broken again to make files of eleven or twelve inches, for there is not so much danger of water-cracks when it is drawn to smaller sizes; and such as he judges not quite sufficiently converted for files, will be suitable for farriers' rasps. So important did the old file-makers consider the best application of their materials, that they generally broke up their bar-steel themselves; but, notwithstanding their care, the anxiety to make hard files caused them to lean towards excessive hardness of conversion, and "water-cracks" were of very frequent occurrence. No other method occurred to them by way of prevention than this—as soon as the files were hardened, to warm them in the fire as much as they could

without tempering them. The fracture spoken of seldom take place while the steel is in the water, but frequently many hours afterwards they are heard to give a sharp click, which may be heard several yards off when the fracture takes place; and they are far more subject to do this in sharp frosty weather, and when the water is very cold, than at other times. Now, on examining the fractures of hundreds of bar-steel files, which an experience of many years has brought under notice, it always appears that the fracture takes place in the middle or least converted part of the steel, and the parts are held together by the outer edges or most highly carbonized parts; in fact, it is the expansive force of those parts which has torn the other asunder. Cast-steel being more homogeneous, is not nearly so much subject to this kind of fracture. It would scarcely be excusable to say so much of the hardening of files, if the greater part of it were not applicable to many tools made of the like material.

When iron has to be united to steel by welding, as in making joiners' plane-irons, socket chisels, &c., shear-steel is used for the common kinds and cast-steel for the best. Good sheer-steel will make good tools; but when ground and glazed, it has a cloudy appearance which cast-steel is free from. In welding shear-steel to iron there is little difficulty; but to weld cast-steel to iron, more skill is required. We shall only instance how cast-steel plane-irons are made. The iron used should not be less than three-eights of an inch thick, and its breadth about two-thirds of the breadth of the intended plane-irons. The steel should be as good as possible, and rolled into rods about one inch and three quarters broad, by full three-sixteenths or barely one-fourth of an inch thick. The iron is first made into what are called moods by drawing and spreading the iron, or thin end of the plane-iron; it is then cut off from the bar, leaving about two inches, to which the steel has to be welded untouched by the hammer. It is then taken by the thin end in tongs, and the other end heated for welding in the hearth-fire, with the usual precautions against oxidation. At the same time, and in the same fire, but not in so hot a part of it, the steel is heated also; and as soon as it is red-hot it is taken to the anvil, and one edge thinned down, then taken to the fire again; and when the iron is at a good welding heat, and the steel as hot as it would be safe to make it, the forger, taking the tongs with the iron in his left hand, and the steel in his right, goes to the anvil, laying the iron upon it, and the steel with its thinned edge towards himself and across the iron; the striker, who is standing ready, gives the steel a few light blows with his hammer, when it will be seen to have its temperature much increased by its contact with the hotter iron; and as the union is to be effected by the iron bringing the steel up to its welding temperature, it is desirable and even necessary in order to ensure the success of the welding, that both iron and steel, in such articles as plane-irons, should be considerably thicker than they will be in the finished state. The hardening of plane-irons and other edged tools, is done by heating them in hearth-fires and plunging them into water; and the tempering is by heating upon a thick cast-iron plate with a fire under: the plate should be kept below a red heat. The tools, rubbed with sandstone that the colours may appear, are

laid upon the plate, several at a time, and attended to by one person; while another, at an anvil, sets them straight while still hot from the tempering-plate. Plane-irons, socket-chisels, and such tools, owing to the expansion of the steel in hardening, are full or convex on the steel side, and the setting is done by putting them iron-side downwards upon the anvil, and hammering the steel with a hammer whose face is slightly convex: by this the iron is extended and the steel brought flat again. But if it be hammered so much as to make the steel side hollow, there is no remedy for it; as any further application of the hammer would only make matters worse by extending the iron still more. Care, therefore, should be taken not to go too far, and also that the blows should not be too heavy, but that they be distributed as equally as possible, not going too near the edge, which endangers breaking the steel.

Fifty years ago, some edge-tool makers had their tools hardened by the forger in the shop in which they were forged, and this was looked upon as a part of the forger's duty. He, feeling no interest in doing this with the care in the heating that ought to be exercised, good steel was often spoiled by carelessness, which led to a different practice; and the hardening of light edge-tools has for many years been made a separate operation, and done by men who do nothing else, and are paid by the day; but unfortunately the practice of hardening heavy tools, such as axes, was continued, in the forging-shop, until British axes got into disgrace in the American market. Time however, and a different practice, will enable us to retrieve this loss.

Cast-steel chisels are set in a different way, by what is called a setting-hammer (Fig. 14), made of very good hard steel, about 1¼ inch × ½ inch in the middle, where the shaft is fixed, and drawn to about 1 inch × ½ inch at the two ends or faces, which are ground convex in the direction of their breadth, and to an obtuse angle in the direction of their thickness. In setting hardened steel articles with this kind of hammer, quite a different method has to be pursued to that already described; for in this case the parts that are full or convex are to rest upon the anvil, and great care must be taken that the part which has to resist the blows of the hammer, beds firmly upon it, otherwise the steel will be broken. The setting of a cast-steel chisel is effected by blows of the setting-hammer across its breadth upon the hollow side of it; the angular face of the hammer cuts to a slight depth into the substance of the steel chisel, and in that manner extends the side so as to make the chisel straight; the same method, in principle, is applied to table-knives, scissors, and some other things.

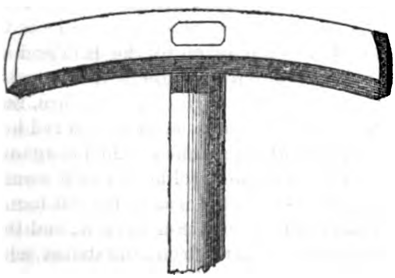


Fig. 14.

Saws are made of cast-steel; and the ingots for all but cross-cut saws are

cast oblong, and from $1\frac{1}{4}$ inch to $1\frac{3}{4}$ inch thick. Cross-cut ingots are cast so that one ingot will make a saw, as represented in Fig. 15; so that when the ingot is rolled end on to the length of the intended saw, it will be nearly the shape required, this shape of ingot being adopted to prevent wasting steel; for it must be understood, that in rolling, the steel extends the way it is put through the rolls, and scarcely at all in breadth. Sheets are rolled square when large circular-saws are made; smaller circular-saws are cut from sheets the breadth of their diameter. Saw ingots are made, both in quality and weight, to suit the particular kinds required. An ingot 29 lbs. weight will make a dozen 26-inch hand-saws; and at the mill it is first rolled into a sheet about five feet long, then cut with the shears into six equal parts, each of which will roll into a sheet 26 inches long and 10 broad, and be the gauge in thickness suitable for that kind of saw. Each sheet is cut in two diagonally, having the point of one saw and the broad end of the other at each end of the sheet. Saw-makers have pattern templets for all the kinds of saws they are in the habit of making; taking a 26-inch hand-saw plate as an example, the templet is laid upon it, and its shape marked upon the steel, the waste part pared off by a pair of strong shears, which, until lately, were worked by hand. Now, however, some of the larger manufacturers, who have steam-engines upon their premises, have shears of a very superior construction to the old ones, worked by steam-power, by which one man can do more work than four could do by the old method, and do it much better.

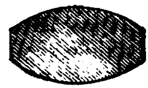


Fig. 15.

Saws are heated in an air-furnace, erected outside the hardening-shop, but communicating with it either by a pair of metal doors opening into the furnace, or one door sliding up and down, and counterpoised like the furnace-doors of a rolling-mill.

Instead of being dipped in water, saws are dipped in oily fluids. Some saw-makers affect to make a matter of mystery and importance of the composition of their hardening fluid. Three kinds will probably comprehend them all; viz. whale oil, tallow, and common yellow resin, in different proportions; or whale oil and tallow; or whale oil simply, without addition. The hardening-shop must have at least two troughs to contain the fluid; one of them long enough to dip the longest saws, and the other round and large enough to dip the largest circular saws. The same care is required, as in the other cases, not to overheat the steel; and also that in taking the plates out of the furnace to dip them, they are not bent with the tongs when being removed from the furnace.

Taking a sheet of rolled steel, of the requisite size and thickness for the required kind of saw, it is cut into the proper shape by the shears as described above; its edges are prepared by filing and grinding, for cutting the teeth. These are formed by a die-cutter, worked by a fly-press, the sheet of steel being moved uniformly forward, after each descent of the die, so as to secure regularity in the distance of the teeth. The rough edges left by the die are removed by filing; and the saw is then fitted to undergo the processes of hardening and tempering. The hardening is accomplished by

heating the saw-plate to a cherry-red, and plunging it into a mixture of resin, pitch, and oily fluids, until it is cold enough to handle. It is now extremely hard and brittle, and is tempered by being passed over a clear charcoal fire, until the unctuous matter adhering to it is burnt off, or, as it is technically called, *blazed*. The saw is now flattened while still warm, and any warping it may have received in the above process removed by hammering; it is then removed to the grinder's wheel. The grindstones vary in diameter according to the size of the saws they are required to grind; to prevent the saw from bending, it is fastened with one face in contact with a flat board, while the other is applied by the grinder to the circumference of the revolving stone. The grindstone is made to revolve with the greatest rapidity, and the grinder presses the board and saw against the stone with the whole weight of his body, moving it from right to left with both hands, so as to secure an even surface. A second hammering now removes any warping the saw may have received in grinding; and an application of it to the heat of a coke fire and flange, until it assumes a faint straw-colour, restores its temper and elasticity. The marks of the hammer being removed by a light application of the saw to the grindstone, the final polish is given by a hard stone, a glazing-wheel covered with buff leather and emery, or a wooden wheel called the *hard-head*.

The saw is now cleaned off, by being rubbed, lengthwise, with fine emery applied by a piece of cork-wood; the next process is called *setting*, which consists in bending each tooth in order, one on one side and the alternate one on the other of the plane of the saw. Perhaps the whole range of the arts does not afford a more marvellous exhibition of manual dexterity, than the manner in which a skilful setter accomplishes this operation. He fixes the saw in a vice, takes a small hammer, gives two or three taps, and then, with a rapid succesion of blows wnich the eye can scarcely follow, he bends each alternate tooth, without missing one or striking two in succession. Marvellous as this is, it is far exceeded by his next feat—he now reverses the position of the saw, and by the same rapid motion of the hammer, strikes the alternate teeth omitted before: a failure of eye and hand here would inevitably spoil the saw, for one tap on a wrong tooth would break it off and consign it to the *waste* basket.

After being set, the saws are placed in a vice between two lead plates, and the teeth sharpened by a triangular file; the handles are fixed on by nuts and screws; and the saws being cleaned and oiled, are placed in brown paper, and are then ready to pass out of the manufactúrer's hand.

Perhaps it may be as well here to remark, that the best way of keeping any article of cutlery which is not in use, free from rust, is to dry it thoroughly and wrap it up in brown paper.

A method of heating steel goods for hardening, which possesses some important advantages over those in common use, has been occasionally practised by a few persons who were in advance of their neighbours many years ago; but it is not so generally known or adopted in Sheffield as it deserves to be; and in recommending its more general use, it should be understood that nothing is said here of a doubtful or merely speculative kind, but that only which has

been successfully practised recommended. Mr. Nicholson, the mathematical instrument maker, when engaged upon some delicate steel work about fifty years ago, said he found the greatest impediment to his success to arise from the difficulty of heating the steel equally; after several unsuccessful attempts he succeeded in finding a remedy by using a bath of lead. Mr. Stodart, cutler and surgeon's instrument maker, more than forty years ago, tells us that he had lately tried this method, and found it to be a great acquisition to the art. To this old testimony in its favour, modern experience may be added; not only when applied to the heating of things an ounce or two in weight, but it can now be said that it answers equally well for articles up to twenty pounds, so that it is applicable to the heating of most kinds of steel goods. The form and size of the bath will of course vary with the form and size of the articles to be heated in it, but should in all cases be considerably larger than the size which a single article of the kind would require, in order that the bath may be kept at a more equable temperature than it could be if it were much affected in that respect by plunging one or even several of the cold articles into it. For this reason, if the bath be intended to heat articles of several pounds in weight, it should be capable of holding not less than five hundredweight of lead. It should be of cast-iron three-fourths of an inch or an inch in thickness, with a broad flange to rest upon, and so set in the brick-work that the fuel can act upon it on all sides, and heat the vessel and its contents red-hot. The room in which it is placed should be well ventilated, and it is well to fix it under a flue with a wide opening at its lower end, like to the chimney of a smith's hearth, in order to carry off any fumes arising from the bath.

At a red-heat the surface of lead oxidizes, but not very rapidly; and if the following precautions be taken to prevent it, the loss from this cause will be very small:—Have a piece of iron to cover part of the lead, leaving only so much uncovered as may be necessary for conveniently dipping the steel and stirring the lead. Iron laid loosely and floating upon the surface of the melted lead is better than a fixed shelf, because, rising and falling with the quantity of lead, it always adjusts itself to it. The other part of the lead-bath should be covered with waste charcoal. The waste charcoal-dust thrown out as useless at converting-furnaces answers very well.

Some of the advantages of this method of heating are so evident, that it is almost unnecessary to enumerate them; but every person accustomed to heating in a hearth-fire knows how difficult, or rather how impossible, it is to heat any instrument with thick and thin parts equally throughout, so that the thin parts shall never become too hot during the heating of the thick part, in a fire which is much hotter than the steel is required to be heated to. Now the lead-bath being heated only to the proper temperature for hardening steel, nothing immersed in it can, however thin, be overheated in any part. It is peculiarly well adapted for razors, surgeons' instruments, and cutting instruments generally. Files, to be heated this way, are prepared in the ordinary manner: the lead leaves the file and does not adhere to the teeth, as might be apprehended. Articles are heated more quickly, as well as more

equally, than in hearth fires; and the saving of time amply compensates the expense of the first outlay and extra cost in fire and lead, in all cases where hardening is the daily occupation of one or more persons.

Cutlery Goods.—In the preceding pages, the steel manufacture of Sheffield has been traced through many interesting stages, by a pen intimately acquainted with the subject; and we feel assured, although the papers are anonymous, every one interested in the subject will see that an able and practical hand has guided the pen, in communicating a mass of real knowledge, such as is rarely laid before the public. In the few following pages we cannot claim the same originality, being indebted for them chiefly to Mr. Wilson's excellent paper "On the Manufacture of Articles from Steel," read to the Society of Arts in April, 1856, and reported in the Journal of the Society.

Mr. Wilson tells us that the steel, as prepared for cutlery purposes, is tilted or rolled to different sizes, suited to the articles intended to be produced. To ensure the necessary degree of hardness, the steel should be compact and dense; it is not considered desirable to use new steel. The reason is not very evident; but it is known, from experience, that steel works 'more kindly' after being kept some time. It is only the makers of first-class cutlery who attend to this, because, to keep a large quantity of steel in stock seems like too much idle capital, though it is necessary in order to obtain the best results. Instead of keeping it in this manner, it is common to use inferior steel, which is softer and easier to work, thus economizing labour and favouring cheapness of production. Another reason for the employment of softer steel is, that it is less liable to waste from cracks or fracture, as will be afterwards explained. The forging of articles from steel is much the same in all cases, except that smaller articles are forged single-handed, and the larger ones by double-handed forges. Thus penknife blades, small scissors, &c., are forged by one man; table blades, razors, edge tools, &c., by two men—a maker and a striker. The maker attends more especially to the form, while the striker, using a heavier hammer, 'draws out' the blade from the rod of steel. It requires several 'heats' to complete the forging of a blade. Small articles of cutlery are mostly made entirely of steel; but the shanks and bows of scissors of large size, and the bolsters and tangs of table cutlery, are made of iron, for the double purpose of economizing steel, and facilitating the labours of those who work after the forgers. The two metals are welded together in a very simple manner. The burning point of steel is much lower than that of iron, and the quality of the steel would be destroyed by heating to incandescence; but iron may be heated to near the melting point without injury. When both are heated to the required degree, they are slightly dipped in a flux, consisting of borax or siliceous sand, and then hammered together. The junction is nearly always visible upon the reverse of table-knives; the iron, not being capable of so high a finish as the steel, appears of a lighter colour. There is one advantage in this appearance—it is a sure indication that the articles have been forged, and not cast. It gives, however, no proof of the quality of the steel. When the forging is completed, the maker's name, as well as any other distinguishing mark that may be

desired, is struck upon the blade, which is then hardened by heating to a red-heat, and immersing it in water. If the steel be good, it becomes excessively hard and brittle; but its temper and elasticity are given by again submitting it to a moderate degree of heat, which a skilful workman can regulate by watching the changing colour of the steel. This will show the reasons for making the bolsters of table cutlery of iron. The latter metal is not hardened by the above process; so that the bolsters of table-knives, and bows and shanks of scissors, can be filed and burnished, or 'dressed,' by any other process, while the blades are so hard as to resist the operation of a file. The process of hardening is so important, that it will not, perhaps, be deemed tedious if I offer a few remarks upon it, especially as it will show the importance of a good feeling between employer and employed. It has already been stated that soft steel is less liable to waste from cracks or fracture. The process of hardening is so delicate, that a slight difference of heat in excess, either in the fire or water, destroys the quality of the steel, or cracks the blades. Cold is equally, if not more destructive; and blades are said to be 'burnt,' 'scalded,' or 'water-cracked,' as the case may be. In forging, too, if the steel be heated too much, its close texture is destroyed, and it has more the appearance of the coarse crystallization of iron.

The next process is 'grinding.' The stones of some parts of South Yorkshire are particularly adapted for this purpose; they are found at the quarries, of a round shape, like a cheese, and of various sizes. Stones for grinding table-knives are about four feet in diameter and ten inches in thickness. To prepare them for running, a hole is made through the centre, in which is inserted the axle. Formerly the stones were fixed upon their axles by means of wooden wedges; but as wood is apt to swell with water, the wedges not unfrequently caused the stones to split, and fatal results were common. Now they are generally held at the sides by a pair of strong iron plates, like quoits, screwed tightly to the stones, which, even thus fastened, not unfrequently break. On the whole, however, they are far more secure, and the accidents resulting from breakages are less serious in their character. When it is stated that these stones make from one hundred to two hundred revolutions per minute, it will be understood that the heat generated by friction between the stones and the blade, under a pressure of several pounds, will be very great; indeed, it is such that a piece of iron or steel would become red-hot in a few seconds. This, of course, would destroy the temper of the blade, and render it unfit for use: to obviate this, the stones revolve in a trough of water, thus keeping the blade cool while grinding it to the required sharpness. The next process as regards table-knives is to glaze the blades; this is done on a large tool called a 'glazier;' it is from three to four feet diameter, and about two inches broad. It is formed in sections of dried wood to prevent cracking; and on this surface, or covered with leather, 'dressed' with emery prepared with beeswax, the blades are glazed several times, until of the required fineness. Spring-knives are ground upon stones from thirty down to nine inches in diameter, and

varying from two and a half to five inches in thickness. The blades are first roughly ground, to reduce them from pieces or lumps of steel to cutting instruments; and to enable the 'cutler,' or 'setter-in,' to fit them to the hafts. It often happens, however, that the edges of the blades are injured before the knife is completeted, so that the edge has to be restored, and the requisite polish given to the blade. This is called finishing, but is the work of the grinders. This process was formerly done upon dry stones, and was considered highly detrimental to the health of the workmen, and many attempts made to remedy the evil. The most successful plan yet introduced is a revolving fan, which is connected with a pipe extending from the front of the stone to the exterior of the building. The action of the fan effects a partial exhaustion of the air in the pipe, and the atmosphere rushing to supply the partial vacuum, carries with it the particles of grit and steel evolved from the surface of the stone. But for the strength of this current these particles would be inhaled by the workmen, and that distressing complaint known as the "grinders' asthma" produced. The dry stone is rarely used in the knife trade, as it is proved by experience that the work formerly done on the dry stone can be done as well on a wet one, with this advantage, that in the use of dry stones, blades were frequently softened by friction; whereas, by the use of a wet stone, such occurrences are rare, though not impossible. The dry stone is as yet, however, indispensable.

When a blade is reduced to a proper strength and elasticity on the edge, which should be done on a small stone, to insure the concavity of its sides, the next process is to give it smoothness and more complete regularity than can be effected on a stone; this is done on a tool technically called a 'lap.' It is a wheel, formed, as before stated, in sections of wood, covered with a surface of lead; this, also, is dressed with emery and beeswax, and greater fineness is given to the steel by the use of vitreous or siliceous stones. For all purposes of utility, the blade is now sufficiently complete; but where a high finish is desired, it is polished by friction with 'crocus,' or oxide of iron, upon a wheel covered with leather. This operation is mostly performed by boys, who begin to learn their trade by finishing the articles upon which they are employed. The blade now only requires to be 'set,' or whetted, and it is ready for use. Some of the more common kinds of cutlery are done on a wooden glazer. The appearance of this work is rather coarse, but good useful blades may be got up in this manner.

The operations in grinding scissors bear so close a resemblance to the above, that to describe them would be a needless repetition. There are, however, some points of difference in razor-grinding that it may be worth while to mention. In manufacturing the better class of razors, it is usual to 'shape' them before they are hardened; and this operation is performed upon a dry stone. The reason for this is, that a stone revolving in water is much softer than when dry; and as the process of 'shaping' is much like scraping the stone away, it will be evident that the use of the dry stone is more economical; and as razors are done on very small stones, there would be considerable loss of time in preparing new ones if thev were worn down

with needless rapidity. The steel also being soft, the operation is more rapidly performed, and no injury is done to the blade by frictional heat. When hardened, the blades are ground upon small stones. The concavity of the sides of some razors may be judged from the fact of the stones being worn down to three inches diameter. Some razors are made still more concave by being ground on a stone with a round surface; but this is a more difficult and costly process, without being attended with corresponding advantages. Good razors may be ground on tools of six or seven inches diameter. This will give the necessary elasticity on the edge, and increased concavity cannot lessen the cutting angle of the edge, on account of the thickness of the back. The finishing process is much the same as in penknives.

The labour and consequent finish bestowed upon the finest cutlery is considerable; but no amount of finish will be satisfactory without good material as the base of the steel; to which frequent hammering, which inferior steel would not endure, gives great density and cohesion. But the commonest goods are produced 'at a heat,' viz. they are 'cast' or 'run.' 'Cast-steel,' however, which bears the palm for cutlery, must not be confounded with articles 'cast' from steel. The former is, as we have seen, highly refined and cast into ingots, then tilted and rolled as before stated. But the steel from which articles are 'cast'—a process of which we have not hitherto made mention—is very inferior; in fact, but one remove from iron. This is melted, and blades 'cast' from it in moulds by dozens, just as any small ornaments or metal-work are cast in quantities. It is called 'run-steel;' but its inferiority is at once evident when tested by elasticity or by fracture. This method saves the cost of forging, and, as may be supposed, is subjected to very little hammering.

It is probable that the system of making things of 'run steel' commenced with scissors, and it would have been well if the manufacture had been kept to its original intention. A cheap instrument was wanted in the wine countries to cut off the bunches of grapes. The acid of the fruit spoilt scissors of the best steel as soon as the commonest; the idea occurred, therefore, of making an exceedingly common article for this purpose, and 'run' steel offered the means of doing this. And as the smallest possible amount of grinding that would give an edge was sufficient for the purpose intended, scissors were produced at prices fabulously low. This was a legitimate use of the cheapening process. But, alas! for honesty, the idea grew. The temptation to produce such goods in imitation of better, for household and business purposes, was too great; and a great trade in rubbish has sprung up—scissors may now be purchased in any quantity at from two shillings and sixpence to three shillings *per gross*.

It is not to be supposed, however, that a metal even so good as 'run' steel is used for these productions. No! the material is baser still—mere pig-iron. Run steel is used for those articles that are made in imitation of first-class goods. When first 'run,' or 'cast,' it is exceedingly brittle, and requires annealing before it is 'made up.' There is necessarily great similarity in the casting of every variety of common cutlery. Table-blades and

forks are cast in large quantities. Some years ago the attempt was made to cast razor-blades in 'run' steel, but the Razor Grinders Union, much to their credit, passed a resolution that they would not grind such rubbish.

Penknife-blades are too small to be made in this manner. They are produced rapidly by means of a fly. The steel is rolled into sheets of the thickness required, cut into breadths equal to the length of the blade intended to be made. The steel is then inserted in a 'bed' of the proper shape, and a stroke of the fly sends a corresponding punch through the steel, carrying with it a piece of rolled steel which is to act as a blade. It will easily be understood that a blade produced in this way is very inferior to one forged from a piece of superior steel. It has neither the compactness nor density which characterise the best class of cutlery. Blades made by the fly-press sometimes go through the process of hardening; but the class of goods thus manufactured is almost invariably of a cheap and useless kind. In grinding, no regard is paid to the *edge* of the article—it is not paid for; and if the surface of the blade be polished, it is all that is required. It has the appearance of a knife, and may be sold as one, although it does not possess the property which should constitute its recommendation and its utility.

The discussion which followed Mr. Wilson's paper, was nót uninstructive. Mr. Moulston, late master-cutler in Sheffield, said that the French cutlers excel ours in their designs for ornamental work, or what he terms "putting together," in the best class of manufactured goods; but he considers them deficient in grinding. The Prussians he found improving very fast, both in tools and cutlery; and he arrives at the conclusion, from these circumstances, that Sheffield, instead of improving and holding its position as other countries have done, has been on the decline. Mr. Moulston goes on to ask some very cogent questions as to the cause of this stationary, if not retrogressing, state; amongst others—why our trade with the United States in axes, long saws, augers, has nearly vanished? He might also have asked, how it is that our own steel comes back to us made into axes and augers, which are eagerly sought after by our own woodsmen?

Mr. Charles Sanderson does not deny the close approach made by the foreigner on one of our great staple manufactures. "Manual labour is cheaper on the Continent than with us," he says; "but their steel is not so good; it is not so well manufactured, nor are the articles put together with the skill and neatness which distinguish our own."

Mr. Mechi considered this manufacture largely affected our national and personal safety. Watch-springs were our mainsprings of punctuality. Needles made from steel-drawn wire were the instruments to clothe us. Our nutrition was dependent on the reaping-hook and scythe. It struck him, however, that Sheffield was pre-eminent in edged tools at the Paris Exhibition. Prussia might be said to stand second in regard to quality and price. On the question of national safety, Mr. Mechi stated that the best steel at £80 per ton was used for sword-blades, and he only wished that the same article had been used for trenching-tools, which were still more necessary to the success of our armies

CHAPTER XIX.

ON THE APPLICATION OF CAST-IRON TO THE MANUFACTURE OF ORDNANCE.

Introductory.—Iron, in an imperfectly malleable state, appears to have been known from a remote antiquity; it is mentioned in Genesis, and there is reason to belive that at an early period it was manufactured in forges by the Persians, Hindoos, and Chinese. Its obvious utility, and great superiority over the softer metals then in use, caused it to be highly prized, though the extreme difficulty of working it, and the rude methods then employed for its reduction, greatly restricted its application. Cast-iron was altogether unknown to the ancients, an imperfectly malleable iron being produced direct from the ores. The rude furnaces then employed would reduce only the richest ores, and even these in small quantities and very imperfectly; but as the means of reduction have continued to improve, the demand for iron has steadily increased, till, in most of the ordinary arts of life, it has superseded every other metal. It is probable that in our own island the manufacture was established antecedently to the Roman invasion; but of its extent we have little knowledge. The Romans carried on a large manufacture, and probably sent considerable quantities through Gaul to Italy. In the forest of Dean, there are large heaps of scoriæ, the refuse of the iron works of the Romans, as is evident from the antiquities found with them; many of these heaps, however, have been re-smelted in comparatively modern times.

At the present time the manufacture is conducted on an immense scale, the annual production in Great Britain being 3,070,000 tons, about equal to that of all the rest of the world put together.

In a previous portion of this work, the process recently announced by Mr. Bessemer has been discussed at some length; and an analysis, along with some comments thereon, quoted from the "Birmingham Journal," the writer of which concludes in these words:—"The amount of iron oxidized by the vivid combustion which Mr. Bessemer's process induces, we are unable to ascertain. The point which most prominently strikes the chemist in Mr. Bessemer's iron is the large amount of phosphorus which it contains—an amount utterly fatal, we fear, to the value of Mr. Bessemer's method."

If this be the fact, and entertaining the same views as the author of these strictures does with regard to the presence of phosphorus in refined iron, we should have great doubts of its ultimate success. It is well known that the puddling process has the effect of removing the phosphorus and sulphur; and as these two elements are highly injurious to the quality of the iron, we must pause before coming to a conclusion as to how far Mr. Bessemer's process is likely to extend the manufacture, or to increase the application of wrought-iron. On the other hand, we, in common with every well-wisher to the advancement of practical science, should most sincerely rejoice at the

approach of any real improvement in the manufacture of iron; and if Mr. Bessemer's process can be realized, we shall hail it as the harbinger of a new era in the application of this most important and most useful material.

We have given the foregoing statements under the impression that in case Mr. Bessemer's process was considered successful, we should then have occasion to enter into the subject of the changes which it would introduce in the application of iron to every useful purpose of construction. But under existing circumstances, where so many doubts are entertained of its ultimate results, we feel it advisable to proceed to the investigation of *iron appliances* as now existing, with such material as the present state of the manufacture commands.

In the following treatise we shall have to treat—first, of the application of crude or cast-iron; and subsequently of the application of malleable or wrought-iron, and of their relative advantages in connection with the constructive and the useful arts.

Cast-Iron Ordnance.—Under the term *Ordnance* are included all those offensive weapons which we call cannon, mortars, or artillery; they are usually constructed of a composition of brass or of cast-iron, wrought-iron having been sometimes employed, but up to the present time with no immediate prospect of coming into general use.

It is a mere conjecture at what period these weapons were first invented. Philostratus speaks of the inhabitants of some city in the Indies throwing thunder and lightning upon their enemies; and some writers contend that they were known as early as the time of Alexander the Great; but all such early accounts are exceedingly vague and unsatisfactory; and although it is asserted by travellers that guns were used in China as far back as the beginning of the Christian era, we are satisfied, if we are to judge from the state of their ordnance during the war of 1843, that little progress could have been made in their artillery practice previous to that time.

The first explicit mention of guns and gunpowder occurs in the works of Roger Bacon, who wrote in the thirteenth century; but they were never practically employed until the time of Schwartz, a German monk, in 1320, for whom is claimed the invention of the arm called the *mortar*. A story is related that some ingredients, which he had been pounding in a mortar, were accidentally set fire to, and exploded with a loud report, carrying the stone which covered it to a considerable distance. This circumstance is more than probable; and hence follows the origin and retention of the term mortar.

Shortly after the discovery of Schwartz, guns began to be employed in warfare; and as casting in iron was then unknown, they were made of strong iron bars like the staves of a cask, strengthened by hoops to prevent their separating during the discharge. Some of these primitive guns are still to be seen at Woolwich and Edinburgh Castle. Others, again, were made of hammered sheets of iron, rolled up and hooped to the form of the gun; but all these constructions were so imperfect, that their employment in warfare was very limited, and they proved almost as dangerous to their possessors as

to the enemy. James the Second of Scotland was killed by the bursting of one of his own cannon, at the siege of Roxburgh Castle, in 1460.

At this early period, not only was the material of the guns defective and the construction imperfect, from want of skill in the manufacture, but it is probable that the gunpowder also was deficient in strength, and was used in small quantities. Hence it was that so long a time elapsed before they were brought into general employment. In 1346, during the reign of Edward the Third, they were made use of at the battle of Cressy, and in 1347 at the siege of Calais. From that time we hear of no improvements in their construction till 1394, when they were employed at the siege of Constantinople by the Turks; and we have reason to believe that the cannon used by them were cast of brass, as they threw balls of 100 lbs. weight, but generally burst at the first or second round. From this time till cast-iron came into use for the manufacture of guns and mortars, we may reasonably infer that they were mostly of brass, and that the old system of hoops and bars was discontinued. At what period iron first came into use for the casting of ordnance is uncertain, but it is supposed that several 32-pounders were cast during the reign of Charles the Second. Mr. Muller was, however, the strong advocate of iron as a substitute for brass; he argues forcibly, and maintains that it is not only stronger, but more retentive of force than brass: and states that "the advantage of useing iron guns in the field instead of brass will be, that the expenses are lessened in the proportion of the cost of brass to that of iron, which is as 8 : 1." And, again, "the only objection against iron is its pretended brittleness; but, as we abound in iron that is stronger and tougher than any brass, this objection is invalid. This I can assert, having seen some that cannot be broken by any force, and will flatten like hammered iron. If, then, we use such iron, there can be no danger of the guns bursting in the most severe action." Such were the views of Muller at an early period of iron-casting; but it was not until after a long succession of years that cast-iron came into general use for this purpose.

The Carron Company in Scotland were among the first to introduce improvements in the manufacture of cast-iron guns; and Mr. Charles Gascoigne, one of the earliest directors of those works, invented, or rather improved, the carronade, which was established as the standard navy gun in 1779. We are not in possession of the mixtures from which these and other guns since cast at Carron were made; but, judging from the strength and other properties of the metals then in use, we should infer, from their durability, that a careful selection was made. Under all the circumstances, it is evident that the material produced at this time by the smelting process was more to be depended upon as an article of commerce than at present. We have only to compare the guns which were cast in the early days of the Carron and Lowmoor Company's works, with those recently constructed, to be convinced of the inferior quality of the iron from which the guns and mortars employed in the last war were cast.

To show the progressive improvement that has taken place in the forms of ordnance, we shall give a few examples of ancient guns: in comparing

them with those at present employed, it must, however, be borne in mind that there is a wide difference between the strength of the gunpowder of the present day, and that which was in use at the time when cast-iron ordnance was first generally employed, and before the new system of compression and granulation with powerful machinery was introduced.

Fig. 1 exhibits a brass gun, executed for the French Government in the year 1718; it is highly ornamental, and of great weight and length. Fig. 2 is a longitudinal section of the same, by which it will be seen that the bore was conical, not cylindrical. This form was adopted to lessen the friction; but the *windage*, or escape of the gas over the ball, must have very much decreased the range. It was found exceedingly difficult to work; and when of large calibre, totally unmanageable.

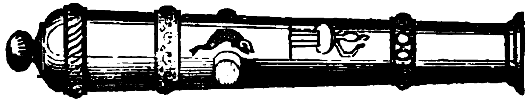
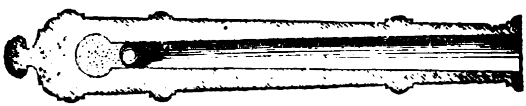


Fig. 1.

Proposals for reducing the weight and great expense of brass guns received considerable attention towards the middle of the last century; and the substitution of iron for brass was carried out by the improvements already noticed. Shortly after the commencement of the iron-works at Carron, it is stated that the armament of the old "Royal George," which consisted of 100 brass guns, weighing 218 tons, and costing £28,340, would, if cast of iron, be of less weight, and cost only about £2100.



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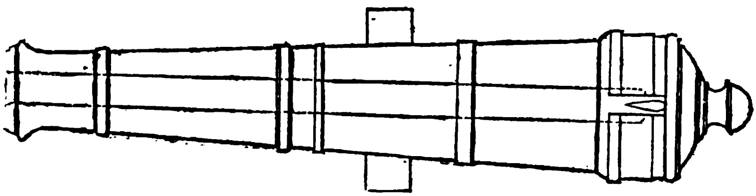


Fig. 3.

This is a low estimate in favour of iron; but the improvements effected by the introdution of the carronade, or short cannon, not only reduced the weight, but increased the efficiency of the gun for service on board ship.

Fig. 3 represents this description of gun, which has been extensively used in the navy for many years past, and has done good service during the days of Rodney, Jarvis, Howe, and Nelson. Fig. 4 represents a howitzer of the same date: this weapon was extensively employed for throw-

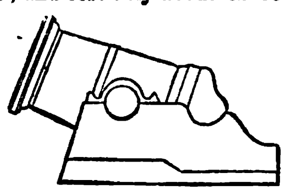


Fig. 4.

ing shells and other missiles on land as well as on ship-board. Since the introduction of steam navigation, and during the late war, the armament of the navy has been immensely increased in weight and power; and the result is a greatly extended range and the employment of heavier missiles.

The object of this inquiry is not, however, a treatise on gunnery, but to trace as far as possible, from the earliest period up to the present time, the application of iron to the arts, destructive as well as useful; to trace the improvements which were made; and to point out the conditions and circumstances under which it may be yet more extensively applied as a material of construction. To attain these objects, we shall have to refer to the writings of those who have so largely contributed to the improvement of the material, as well as its application; and also to those researches in experimental science, which have rendered its strength and other properties familiar to the iron-founder and the engineer.

In regard to the advantages of iron over every other material at our disposal for the construction of cannon, little need be said; its strength, density, rigidity, and cheapness, all point out its great superiority. But another question arises, not so easily settled—In what form should it be employed, whether as cast-iron, steel, or wrought-iron? Up to the present time, wrought-iron has not been, in a general sense, applied otherwise than experimentally; however, as our readers have seen in Mr. Clay's paper on Wrought Iron, the monster wrought-iron gun, so far as the experiments have proceeded, has yielded very satisfactory results.

Attempts were made some time ago to substitute steel for cast-iron in the manufacture of artillery. Herr Krupp, of Essen, one of the most distinguished steel manufacturers in Europe, proposed cast-steel as a material for ordnance in the year 1847; and his first gun, a 3-pounder, was submitted to very severe tests at Berlin in 1849, under which it finally burst. In 1855, a 12-pounder of the same material was sent to this country, which withstood very severe tests. About the same time a cylinder of cast-steel was sent from Essen, which was bored to the calibre of an eight-inch gun; and when here it was cased in a cast-iron jacket. The cast-steel gun weighed five tons, the casing four tons. It was tried at Woolwich, and burst on the first fire, with a less weight of powder than the ordinary proof-charge. This failure seems conclusive as to the inefficiency of steel as a substitute for iron; more especially when we consider its enormous cost. Hence it is that we consider cast-iron, when properly prepared, to be superior to every other material for the construction of ordnance; but great care requires to be exercised in the selection of the iron, and in its preparation.

Until the period when coal was first applied to the reduction of iron ores in place of charcoal, a much purer iron was obtained than at present. The crude iron produced from the charcoal furnace was generally much more free from phosphorus and sulphur; and consequently a much more tenacious metal, admirably adapted for casting artillery and heavy guns, was obtained. But since the employement of coke, and more particularly since the application of the hot-blast, and the use of raw coal, the iron-master has been enabled to

increase his production ten-fold; and such are the facilities afforded by the enormous reductive power of mineral fuel, that he is tempted to increase the quantity at the expense of the quality, both by too rapidly forcing the smelting process, and by the use of impure materials. It is true that although this increasing and cheapening the process is a legitimate object on the part of the manufacturer, it is nevertheless not calculated to produce iron suitable for artillery. When a metal is required for such a purpose, the greatest care should be observed in its preparation. Charcoal-iron, when it can be obtained, is undoubtedly the best; and it will be found advantageous to remelt it several times before casting, if it be of No. 1 or No. 2 quality.

In selecting iron for guns, the American government has adopted the plan of testing the quality by a breaking machine, by which the tenacity of the iron is shown in its powers of resisting a tensile or transverse strain. This machine is useful to the iron-founder in selecting his material in every case where strength and tenacity is the object to be attained.

In some experimental researches undertaken by Mr. Fairbairn, at the request of the British Association for the Advancement of Science, and published in their Proceedings in 1853, the effects of remelting upon a fine quality of Eglington hot-blast iron, No. 3, were tested, and it was ascertained that it did not reach its maximum power of resistance until it had been remelted twelve times; and from thence to the fourteenth melting it deteriorated rapidly, as may be seen by the following table of results :—

No. of melting.	Specific gravities.	Mean transverse breaking weight; lbs.	Mean ultimate deflection; inches.	Power to resist impact; lbs.	Resistance to compression per square inch in tons.
1	6·969	490·0	1·440	705·6	44·0
2	6·970	441·9	1·446	630 9	43·6
3	6·886	401·6	1·486	596·7	41·1
4	6·938	413·4	1·260	520·8	40·7
5	6·842	431·6	1·503	648·6	41·1
6	6·771	438·7	1·320	579·0	41·1
7	6·879	449·1	1·440	646·7	40·9
8	7·025	491·3	1·753	861·2	41·1
9	7·102	546·5	1·620	885·3	55·1
10	7·108	566·9	1·626	921·7	57·7
11	7·113	651 9	1·636	1066·5	69·8
12	7·160	692·1	1·666	1153·0	73·1
13	7·134	634·8	1·646	1044·9	66·0*
14	7·530	603·4	1·513	912·9	95·9
15	7·248	371·1	0·643	238·6	76·7
16	7·330	351·3	0·566	198·5	70·5
17					
18	7·385	312·7	0·476	148·8	88·0

* In the thirteenth experiment the cube did not bed properly upon the steel plates, otherwise it would have resisted a much greater force—probably from eighty to eighty-five tons. It is also to be observed that there is some accordance between these experiments and the similar ones on malleable iron reported in Mr. Clay's paper, at page 318, where the greatest resisting force occurred at the sixth heating.

The results on transverse breaking-weight were obtained from experiments on bars of one inch square and four feet six inches between supports: those on impact were calculated by multiplying the transverse breaking weight by the ultimate deflection; and those on compression by experiments on three-quarter inch and five-eighth inch cubes.

Other experiments were undertaken, but they varied considerably from the above; some specimens attaining their maximum strength at the third or fourth melting. In order to determine the value and resisting power of cast-iron under different modes of treatment in the preparation of metals, Mr. Fairbairn was requested to undertake a series of experiments on 24-pounder guns, under the direction of the Board of Ordnance; and as these experiments exhibit important results, we are probably justified in giving the following abstract from the Reports of the Royal Artillery Institution:—

Mr. Fairbairn's Experimental Cast-Iron 24-Pounder Guns.—Six experimental 24-pounder iron guns, each nine feet six inches in length and fifty cwt. in weight, were cast under the direction of W. Fairbairn, Esq., by the Bank-Quay Foundry, during the months of August and September, 1855; the greatest possible care was used in selecting the strongest and purest metal, and in every process connected with the casting. The guns were lettered A, B, C, D, E, and F.

"A—Cast from the Bank-Quay Foundry mixture, consisting of:—

Blaenavon cold-blast	No. 1	2 cwt.	43 cwt.
	No. 2	15 ,,	
	No. 3	26 ,,	
Lilly's Hall cold-blast	No. 3		32 ,,
Pontypool cold-blast	No. 3		15 ,,
		Total	90 ,,

"B—Cast from pig-iron remelted once, and then run into the mould in the usual way.

"C—Cast from the Bank-Quay Foundry mixture, run from the cupola and remelted by desulphurized coke.

"D—Cast from the Bank-Quay Foundry mixture under a dead-head pressure of thirteen feet nine inches.

"E—Cast from pig-iron remelted once, and then run into the mould under dead-head pressure.

"F—Cast from the Bank-Quay Foundry mixture, with a core in the centre. The great heat caused the iron core to adhere to the metal, and the cast was consequently a failure.

"The guns marked A, B, C, D, E, were gauged, examined, and proved in the Royal Arsenal on the 9th and 23rd, October, 1855, and then removed to the Butt in the marshes for experiment. The experiments were commenced 30th November, and were terminated 21st December, 1855. The charges used were as follow:—

No. of rounds.	Powder.	No. of shot.	Wads.
5	8	2	2
5	8	3	2
5	10	3	3
2	10	4	4 C burst.
3	10	4	4
5	12	4	4
2	12	5	5

"Cylinders averaging 144 lbs. in weight, or equal to six shot, were here substituted for the shot, and the experiment continued:—

No. of rounds.	Powder.	Cylinder.	Wads.
2	12	144 lbs.	1
2	14	144 ,, and 1 shot.	1 D burst.
1	14	144 ,, ,,	1 B burst.
1	14	144 ,, ,,	1 A & E burst.

"The severe test which these guns stood before bursting, affords a satisfactory proof of the value of good cast-iron as a material for ordnance, provided the metal be properly prepared and judiciously treated during the process of casting. It will be observed that C gun burst at a comparatively early stage of the trial; this appeared to have been caused by fragments of shot broken by contact with each other within the bore. On commencing the experiment, the guns were placed on the ground, and their muzzles supported by blocks of wood, as is usual in the proof of ordnance. Sods of earth, and holes dug in the slop of ground in the rear, somewhat checked the recoil. After a time, when the guns were heavily shotted, the recoil became so great that other means for checking it became necessary; beams of wood were driven horizontally into the bank, and the button of each gun brought against the end of a beam; the beams were, however, soon split. Heavy piles of timber were then driven into the ground in the rear, and supported by cross-beams; this formed a bulkhead which effectually resisted any further recoil.

The number of pieces into which each gun burst varied from fifteen to twenty-four, besides many small fragments: large pieces were thrown considerable distances; one piece fell seven hundred yards to the right. In every instance but one, when the guns burst, the shot or cylinders and shot were driven into the Butt as usual. In the case of A, the exception alluded to, one half of the cylinder was found among the fragments of the gun. It appeared evident that this gun had burst before the inertia of the charge had been completely overcome, and that the cylinder was broken by contact against the fracture of the bore.

"It will be seen that A and E guns stood the greatest number of rounds. From an examination of the granular character of the fragments of both guns, it was concluded that the metal of E was the best. In this opinion Mr. Fairbairn concurred. He attributed the closer and stronger grained metal partly to the remelting of the iron, and partly to the great length of dead-head, seventeen feet three inches; and it will be admitted that both guns stood an exceedingly severe test."

The following table gives the number of rounds, weight of metal discharged, and quantity of powder used, in the above trials:—

Mark on gun.	No. of rounds.	Quantity of powder used, in lbs.	Total weight of shot, in lbs.	Weight of fragments.	Projected to a distance of
A	33	364	3120	2½ cwt.	256
B	32	350	2952	2½ "	300
C	17	150	1152	4 "	300
D	31	336	2784	5 "	450
E	33	364	3120		700 or 800

From a volume of "Reports of Experiments on the Strength and other Properties of Metals for Cannon," published by the Government of the United States of America, and presented to the writer of this article by the intelligent experimenter, Mr. Wade, we have extracted the following results, which may be valuable in connection with all cast-iron constructions where great strength is a desideratum.

To ascertain in what manner the quality of iron was affected by its continuance in fusion, exposed to an intense heat, for longer or shorter periods of time, four 6-pounder guns were cast and tested in the usual way by firing. The charges were so arranged as to give a gradually increasing force at each successive fire up to some convenient maximum, and then to continue that till the gun burst. Thus, commencing with two pounds of powder and two balls, the charges were gradually increased till they reached the maximum charge of three pounds of powder and sixteen balls, at the twenty-third fire; this charge was continued till the thirty-sixth fire, and then the only gun remaining was tried with two charges of six pounds of powder and seven balls. The results are given below:—

Iron in fusion. Hours.	No. of fires made.	Powder used. lbs.	No. of balls discharged.	Endurance.
½	31	75	367	Burst at 31st fire.
1½	34	84	415	Burst at 34th fire.
3	38	102	461	Remains unbroken.
3¾	25	57	271	Burst at 28th fire.

It would appear from the above, that the three hours' fusion gave a maximum result of tenacity with this iron; and Mr. Wade considers that these facts satisfactorily prove that a prolonged exposure does augment the cohesive strength of iron up to some limit not yet well ascertained; but that if extended beyond that limit, the strength of the iron is thereby diminished. The same increase of strength was apparent in some experiments on bars. In most irons, extended fusion has the effect of producing increased tenacity; but this increase of strength is more apparent in iron from the air-furnace than from the cupola, and the utmost care is required in some irons not to exceed the limits at which fusion is satisfactorily attained. This point is generally determined by the practised eye of the furnace-man and founder.

In 1851, Mr. Wade made some very successful attempts to cast guns hollow, and to cool them from the interior. The moulds of two 8-inch colum-

biads were placed in open pits: one of the castings was made solid and cooled in the usual manner; the other was cast hollow by means of a core formed on a tube of cast-iron, through which a stream of water circulated while the iron was cooling. The core-tube was closed at the lower end, the water being conducted to the bottom of it by an interior tube placed in the centre of the core, and rising in the annular space between the tubes, flowed off above the casting in a heated state. The exterior of the mould was heated so as to prevent its cooling there. Two 10-inch columbiads were also cast, one solid, the other hollow as above, excepting that the exterior surface was allowed to cool more rapidly. They were tried by continuous firing in the usual manner, and the following results were obtained:—

8-inch gun, No. 3, cast solid . . 73 fires.
8-inch gun, No. 4, cast hollow . . 1500 fires.
10-inch gun, No. 5, cast solid . . 20 fires.
10-inch gun, No. 6, cast hollow . . 249 fires.

The 8-inch gun, No. 4, remained unbroken, apparently capable of much further service. Samples taken from different parts of the burst guns, showed great uniformity in the tenacity of the specimens; the mean density of thirty-eight specimens being 7·290, and the mean tenacity 37,800 lbs. per square inch. The following table gives the results of these and similar trials exhibited at one view:—

Date.	Description.	Quality of iron used.		Rounds fired.	
		Density.	Tenacity.	Cast solid.	Cast hollow.
1849	First pair, 8-inch . .	7·223	27488	85	251
1851	Second pair, 8-inch .	7·287	37811	73	1500
1851	Third pair, 10-inch .	7·292	37817	20	249
	Total No. of fires .	..	..	178	2000
1844	Trials made in Boston, both guns cast solid, 8-inch	7·276	26367	731	..
	10-inch	..	..	612	..

Mr. Wade believes that this great difference between guns cast hollow and those cast solid, could not have been caused by any accidental causes, the guns being cast in pairs together, and every precaution being taken in the manufacture and proof to secure uniform results. This must therefore be ascribed to the different methods by which the castings were cooled. But the anomalous results, that guns cast of iron of the same density and tenacity afford a different endurance when tested by gunpowder, must be explained by the laws which govern the contraction of iron when cooling.

On this subject, Mr. Wade observes that "it is known that the contraction under equal reductions of temperature is different in iron of different qualities; soft gray iron, which contains a high proportion of carbon, con-

tracting least; and that which founders term high, which is hard, light, and close-grained, and contains the least per-centage of carbon, contracts most, other circumstances being equal. The contraction of the same iron is greater or less, according to the greater or less rapidity with which it is cooled. That which is cooled most rapidly, contracts most."

The utmost care and attention is required on the part of the engineer and iron-founder, to regulate the cooling and contraction of metals. In the province of the former, it is of primary importance that the design and arrangement of the parts of castings should be such as to insure, as far as possible, uniformity in the shrinkage, so that there should be equal tension in all the parts. Nothing is so dangerous in cast-iron constructions as the unequal tension arising from contraction; and in cases where castings, either from necessity or otherwise, have their parts varied in thickness or position, it requires consideration on the part of the iron-founder to retain the fluidity of the thinner parts as long as possible, and to accelerate, with proper precautions, the cooling of the parts which contain increased quantities of metal. In the very centre of castings, a principle of insecurity and danger exists, which not unfrequently tears the parts asunder with a loud report. Careful consideration in the caster will, in most cases, obviate this evil. In the casting of ordnance, Mr. Wade observes, that a large mass of metal, like a heavy gun, cools from the exterior, a thin external crust being first formed; then, on the interior of this, a second; and so on towards the centre. Suppose that just as all the liquid iron has become solid, the exterior has cooled down to the temperature of the atmosphere, there would then be a difference of temperature of 2700° between the exterior and the interior. At this time it would be entirely free and unstrained by contraction; "but as the exterior of the casting has cooled down to a temperature at which contraction has ceased, and the interior remains at the melting point, 2700° higher, the contraction due to the latter ($\frac{1}{81}$ part of its linear dimensions) is yet to occur in the centre, after the exterior has ceased to contract. The effect of such a contraction *must be* to exert a strain of compression on the exterior, and one of elongation on the interior. The above supposes an extreme case, in which a maximum of difference of temperature between the exterior and interior occurs—a condition which never occurs in practice. But it serves, nevertheless, to explain the law which governs the contraction of iron, and what is believed to be its injurious effect in castings which are unequally cooled. What remains undetermined, is the exact measure of the consequences of such strains.

"In the case of the 10-inch gun cast solid, which burst at the twentieth fire (being of large diameter, and made of very high iron, both contributing to a large contraction), it is supposed that the strain thus produced was nearly sufficient of itself to split the gun, and that a few shocks only from the firing were required to complete its destruction."

Comparing the two guns cast solid in 1851 with these cast in 1844, we find that the former, made of high iron, giving a mean test strength of 37,814 lbs. per square inch, endured only a mean of 46 fires; but that the

latter, made of lower iron, giving a test strength of only 26,367 lbs., endured a mean of 671 fires. This was, in all probability, in consequence of the greater contraction of *high* iron. "From this it appears, that a reduction of strain in the casting is of more practical value than an increased strength of the iron." Hence, either the hard strong irons must be abandoned in the manufacture of heavy ordnance, and soft gray qualities substituted, or some means must be adopted for so regulating the cooling process as to prevent the existence of a strain arising from unequal contraction; and this last seems to be effected, in part at all events, by Lieutenant Rodman's plan of casting with a core.

Subsequently to the above, two other 8-inch columbiads, cast solid, were tried by firing, and gave the following anomalous results:

	Density.	Tenacity.	No. of fires endured.
Cast and proved in 1851 (see last table) :	7·287	37811	72
Cast in 1846, and proved in 1852 . : :	7·247	29423	2582
	7·220	22989	800

"The form, dimensions, weight, mode of casting and cooling, and the manner of proving, were the same in all. It will be seen that the gun made of the strongest iron, with a short interval of time between its manufacture and proof, endured the smallest number of fires; and that those made of weaker iron, but proved long after being cast, endured the greatest number."

It is well known that beams, &c., submitted to severe strain, tend, in course of time, to accommodate themselves to the position they are forced to assume, and by some molecular change acquire a large permanent set, their tenacity being little injured. The above anomalous results are probably explained on this principle—a molecular change having taken place in the course of some years, and the strain produced by unequal contraction being relieved, would permit all the resisting powers of the metal to be opposed to the force of the charge.

This change will occur the more rapidly, if another strain be opposed to that produced by unequal contraction. If, for example, a cast-iron beam (Fig. 5) has a thick flange on the bottom side at B, and a thin one on the other, the tendency would be for the thin side to solidify some time before the other had cooled down to that point. In the act of cooling, the contraction of the metal of the thin flange would tend to give it a concave form; but afterwards the larger mass of metal in the thick flange, passing from the fluid to the solid state, and contracting still more forcibly, would force the upper flange into a convex form, as shown in Fig. 5; and ensure a considerable tension in flange A, by bending the beam upwards, and forming a concavity on the under side, B. A beam or casting of any kind, therefore, having one side in a state of tension and the

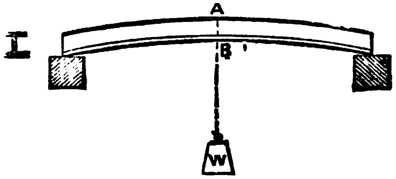


Fig. 5.

other in a state of compression, with its cohesive powers below uninjured, is precisely in the most favourable condition for sustaining a load. It is evident that, in submitting a beam of this kind to strain by suspending a weight from the middle, as at W, its bearing powers are improved rather than diminished. By increasing the weight till the deflection of the beam relieves the tension on the upper flange, by forcing the particles together and throwing a tensile strain, on the lower flange, the beam is in the same condition for supporting a load as if no strains had been produced by contraction in cooling.

In the case of cannon cast solid, the strains produced by contraction, acting in the opposite direction to those we have spoken of, tend to burst the gun and weaken it, by acting in the same direction as the strain produced by firing.

Viewing the subject in this light, it will be found that the power of resistance to strain is constant, when the load remains uniform and undisturbed. Thus, if the beam (Fig. 5) were loaded to within 1-100th part of its breaking weight, it would continue to support that load *ad infinitum*, if it remained undisturbed and without change. In this condition, the whole of its powers of resistance are brought to bear upon the load. Reverse the process by removing the load, replace it, and continue this operation of removing and replacing for some time, and the strains produced will be similar to those of the guns which were burst by repeated charges; each of which, by itself, was far from sufficient to seriously injure them. By such repeated strains, the melecular cohesive power of iron is destroyed; and the real question for solution is, to what extent may we continue these changes before fracture ensues. By the table just recorded, it will be seen that one of the 8-inch guns sustained only 251 fires, while another remained unbroken after 1500 fires.

In all constructions such as cannon, it is essential that the greatest care should be taken in casting to have the metal perfectly liquid, and of the right temperature; to give time in the cooling: and to assist the natural process of crystallization, so as to allow the crystals to form regularly, in order to insure uniformity of tension in all the parts. In the selection of iron for the casting of artillery, the greatest circumspection should be observed to obtain it free from sulphur or phosphorus. The metal should, in our opinion, be ductile, but closely granulated, and of a specific gravity not less than 7·2. Iron of this kind, smelted either by coke or charcoal, is generally found to possess great tenacity; and, if properly prepared, by remelting a few times, according to the quality of the iron, we may reasonably conclude that guns may be cast that will stand from 1500 to 2000 rounds before they are disabled, and from 1000 to 1500 before they are pronounced unfit for service.

CHAPTER XX.

ON THE APPLICATION OF CAST AND WROUGHT-IRON TO MILLWORK AND MACHINERY.

It would be interesting to trace the first development of cast and wrought-iron appliances to millwork and machinery; but the subject is so much involved in obscurity, and even the time of its introduction is so uncertain, as to render this impossible. There cannot exist a doubt that it was employed at a very early period as a substitute for brass, or, as it was then called, gun-metal, in the manufacture of cannon. It is asserted that there was an export of cast-iron ordnance to the Continent as early as the reign of Elizabeth. Since that time there has been a progressive extension and improvement of the smelting manufacture and casting of iron, and of its application to a variety of structures, such as steam-engines, architecture, bridges, and machinery. One of the earliest and most extensive applications of iron was opened up by the Colebrookdale Company, by their castings for the iron bridge which crosses the Severn at Colebrookdale in 1777—9, and also the bridge at Sunderland, one of the most stupendous structures of its kind at a time when iron constructions were but little known and imperfectly understood. From that time we may date the commencement of a new era in the application of cast-iron to the constructive arts.

About the same time, Mr. Watt availed himself of the advantages of iron, which could be run into moulds, for the construction of the steam-engine. Without the advantages derived from casting, and the facilities it gives to the multiplication of forms of every description, steam-engines and other constructions would be extremely limited and imperfect; but with the aid of the foundry and the forge, we are enabled to combine every form, and to meet all the requirements of an enlarged and increasing consumption.

Of what advantage would the construction of the steam-engine, millwork, and machinery be, if it were not for the facilities and cheapness with which these constructions are effected by the use of cast-iron? and how laborious and expensive would it be, if we had to form our cylinders, pumps, and steam-pipes out of wrought-iron or brass! The expense would be enormous, and the manufacture also imperfect; hence the advantages we derive from the use of iron in the crude state, when it can be moulded and run into almost every shape. We shall endeavour to give, in consecutive order, the various uses to which it is applied; and, by comparing the present with the past, we shall be taught how much we have learnt, and how much we have yet to learn, in all its appliances to mechanical construction.

It is not more than a century since toothed wheels for communicating motion were made entirely of wood; and there are still in existence specimens of the *cog and rung*, with large wooden shafts, to mark the state of the mechanical arts at a time not much beyond the memory of persons still

living. We ourselves remember to have seen one of the first iron wheels that was cast in Scotland; and we believe it to be still in existence, as the base of a dial-plate in front of the residence of the late Mr. Wm. Murdock of Soho, near Birmingham. Since then, mill-gearing has undergone a wonderful change, attributable almost entirely to the use of cast and wrought-iron. As an example of the state of mill-work little more than eighty years ago, we give the following sketch, showing the mode of construction as it then existed, for comparison with the manner in which the same is effected at the present day. Up to the year 1780, most of the mills in this country, and other parts of Europe, were driven by wooden wheels and shafts of the annexed form.

In this figure of a corn-mill (Fig. 6), A is the water-wheel put in motion by a stream of water, B, the pit-wheel, and C, the upright shaft or stone spindle; and on this shaft the running-stone was fixed. At other times, when more than one pair of stones were required, a spur-wheel and pinion (technically called "cog and rung") gave motion to three or four pairs. All the wheels and shafting were of wood, constructed like the pit-wheel B, the teeth being composed of hard wooden pegs; and the pinion, or "wallower," as it was then called, was constructed of round pegs or trenails, inserted into and between two circular discs, as shown in the drawing D, Fig. 6.

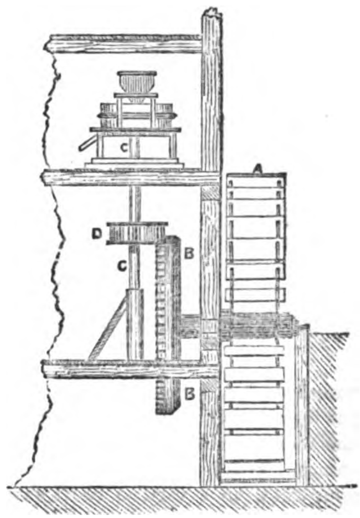


Fig. 6.

Contrasting these with the constructions of the present day, as practised by our most eminent engineers, we perceive at once the immense benefits conferred upon practical science, and the facilities afforded for the advancement of the constructive arts, by the application of iron in its crystalline as well as its malleable state. The wheels, shafts, and supporting framework, generally denominated fixings, can be reproduced or multiplied to any extent by casting from the original model. It is in this that the use of cast-iron differs from that of malleable iron; for, although the strength and ductility of this material is greatly increased by being converted into the malleable state, yet each wrought-iron article has to be forged separately, and then planed and turned to the required shape, while by the casting process we are enabled to produce articles of every variety of form, and often of exquisite beauty, in the decorative as well as the useful arts; and once having made a model, we may produce any number of copies that may be required.

The accompanying sketch (Fig. 7) shows the changes which have been effected in the construction of corn-mills by the use of this material. A steam-engine is in this case the moving power which gives motion to a hori-

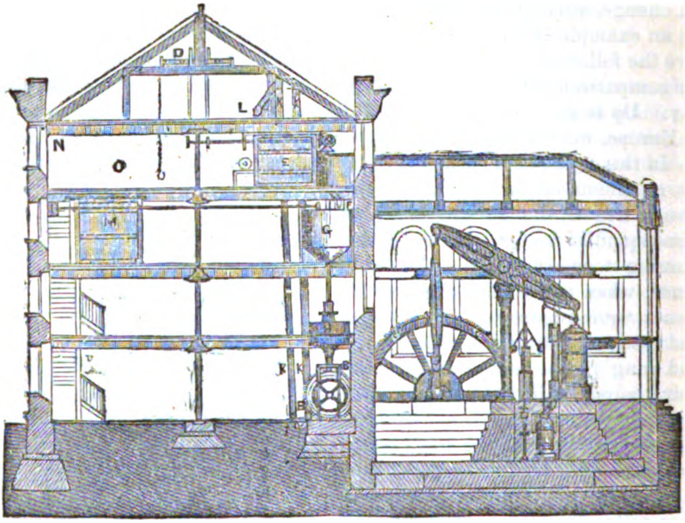


Fig. 7.

zontal shaft A, by means of the pinion B, which works into the periphery of the fly-wheel C of the steam-engine; and this again communicates motion of the required velocity to the vertical spindles of from six to twenty pairs of stones. This is a great improvement over the old plan, in which a toothed spur-wheel on a vertical shaft gave motion to from three to four pairs of stones, and where all the wheels had to be framed of wood.

The wheat, as it arrives, is raised to the top of the mill, sometimes by the hoist or teagle D, or by elevators; and from thence it is conveyed to the wheat screening-machines, one of which is seen at E. From these machines it passes into the Archimedean creeper F, which runs along the whole length of the building, and distributes the wheat equally through all the hoppers G. Thence it falls into the stones which are inclosed in iron cases, H, the supply being regulated by the silent-feeder. After being ground it falls through the inverted cones into the Archimedean creeper I, which conveys it to the end of the building, whence it is raised by another line of elevators K K, to the creeper at N; and from thence it is passed to the cooling room O, and the dressing-machines M, where it is separated from the bran, and prepared for the market. In addition to the principal driving gear, the frames and inverted cones are composed of cast-iron; and the spindles and lighter shafting for driving the cleaning and dressing machinery in the

rooms above, are constructed of malleable iron, carefully turned and finished, and fitted with the greatest accuracy to their bearings.

The flour mills of the present day are, moreover, made self-acting, by the use of Archimedian screw-creepers (similar to those occasionally employed for raising water), and other elevators and appendages, which carry on a consecutive process in the manufacture. This description of machinery could not have been executed but for the extensive use of iron, and the improvements introduced by Mr. Fairbairn in the system of gearing direct from the fly-wheel, placing the mill-stones longitudinally, in a straight line, and adopting the silent-feeder for supplying the stones with grain. All these improvements give a degree of neatness and durability to the machinery that could not have been accomplished where wood was employed as the only material of construction.

It is not, however, in corn-mills alone that iron has produced such changes. It has introduced still greater improvements in the machinery for transmitting motion to the different machines employed in the manufacture of the textile fabrics. The writer recollects the ponderous shafts and heavy drums of former days, which used to utter groans and loud complaints at every revolution; and he attributes much of his own early success in life to the changes effected by the increased velocity, and great reduction of weight in machinery, accomplished by the employment of iron.

Like every other improvement, it was at first sturdily opposed; but opposition at last gave way to the numerous advantages—such as economy of

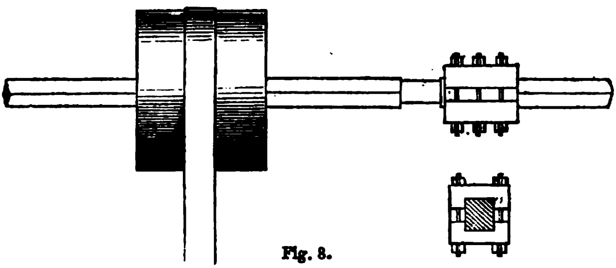


Fig. 8.

power and cost of construction, greater durability, accuracy, and exterior finish, with a perfectly noiseless motion—which these changes introduced.

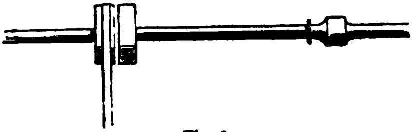


Fig. 9.

The annexed sketch, Fig. 8, exhibits the form of a horizontal shaft and drum, as it existed in some of our cotton-mills fifty years ago; and Fig. 9 the same as it is now constructed.

From the above it will be evident that a very considerable saving of power, as well as of material, has been effected by the substitution of light shafts at high velocities for the ponderous heavy shafting, which could only be run at low speeds, and then with

an enormous amount of friction. Fifty years ago the requisite speed for the machines was obtained by a wooden drum from four to five feet in diameter; now it is obtained by a light iron pulley and polished iron shaft, running at three to four times the speed. The shaft and drum, Fig. 8, running at 30 to 40 revolutions per minute, represent things as they were fifty years ago; and Fig. 9, at 100 to 140 revolutions per minute, shows them as they now exist. All these changes, improvements, and alterations, are attributable to the free use of iron.

Before entering upon another department of iron appliance, it may be interesting to give one or two more examples of the iron constructions in mills appropriated to the manufacture of cotton, wool, and other fibrous substances; and to endeavour to show how largely the use of iron in their construction has contributed to the skill, spirit, and enterprise with which the manufactures of this country have been pursued, and from what comparatively small beginnings the present system of organization has originated, standing as it does without a parallel for its immense exent and vast national importance.

Without iron, and the facility and cheapness with which it can be applied to the construction of millwork and machinery, the inventions of Arkwright and Crompton would have been a dead letter. The fire-proof mills, the steam-engine, and the shafting by which its force is transmitted to distances of many hundreds of feet, are among the proofs of the value of iron appliances. When we add to these, the beautiful machinery which receives its motion from the iron arms of that gigantic power, the steam-engine, some conception may be formed of the immense value of this extensive and widely-extending manufacture. Some idea may be formed of the demand for iron for these constructions when we state, that in this country alone the cotton manufacture employs upwards of 1,000,000 spindles constantly in spinning yarn. Upwards of 250,000 power-looms are in operation, independently of hand-weaving; and to these must be added carding, roving, winding, and dressing machines; and even then we are far short of an accurate estimate of their extent and value, or of the iron required to keep up the supply. This can only be arrived at by a regular course of statistical returns; but as these do not constitute a part of the present investigation, we are enabled to supply only such data as may be calculated to show the amount of demand and the application of iron in cases where nearly the whole of the machinery, millwork, and steam-engines, are composed of that material. In corroboration of what has already been said, let us take a single mill in the hands of one person, in which the motive-power is supplied by engines of 1200 to 1800 indicated horse-power, driving 70,000 spindles and 2500 looms. These works now in existence are divided into two mills, one driven by a force of 600 nominal horse-power, the other by a force of about half that power. As the former is one of the latest constructions, it may be necessary to give a brief description of its arrangements, more particularly in reference to the conditions, forms, and purposes to which iron is applied in connection with this large and important branch of industry.

Fig. 10 exhibits a longitudinal section, and Fig. 11 a plan, of one of those establishments. A, in the ground plan, represents the steam-engines, one on

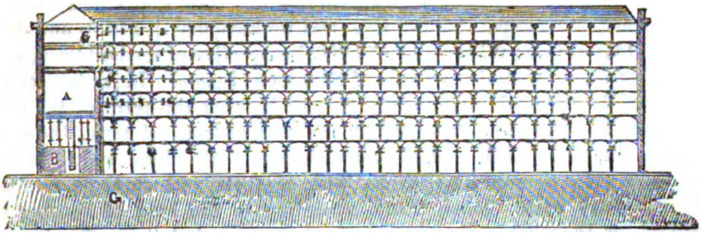


Fig. 10.

each side of the fly-wheel B, which gives motion to the whole of the machinery; the mill is 310 feet long and 60 feet wide, and six stories high. It contains 12480 square yards of flooring, and the two lower stories are occupied by carding and preparatory machinery; the four rooms above by spinning machinery. The large building D, containing an area of 6760

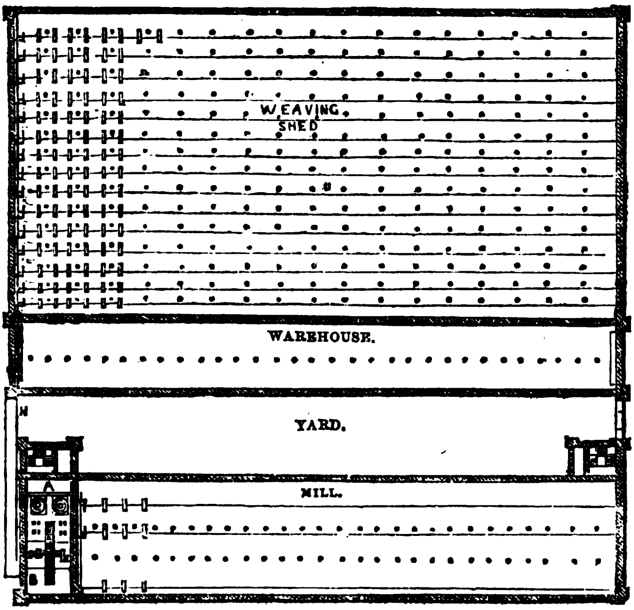


Fig. 11.

square yards of flooring, is appropriated exclusively to power looms; and from these (1800 in number) are produced 50,400 yards of cloth per diem. The whole of the machinery contained in this space and the two lower floors

of the mill is composed of iron, and weighs about 960 tons. The mules and throstles of the four upper rooms are also of iron, and weigh upwards of 250 tons. Add to these the steam-engines and boilers 400 tons, millwork and steam-heating apparatus 700 tons, and we have 960 + 250 + 400 + 700 = 2310 tons of iron; value about £70,000, irrespective of the buildings, which are fire-proof, and contain upwards of 2000 tons of metal. In the longitudinal section of the mill exhibited in Fig. 11, will be seen the form of the floors, consisting of iron beams supported on two rows of iron columns; the spaces between the beams being arched over with brick. On these arches are laid the floors, on some occasions covered with concrete, with stone flags or tiles, and at others with wooden floors, according to the kind of flooring best adapted for the machinery contained in the rooms; but these structures we shall have occasion to notice more at length when we come to treat of iron as applied to architecture.

It will be observed that the steam-engines A and the fly-wheel B give motion to the horizontal shafts, and these again transmit it to two vertical shafts (one of which is shown at G G), which rise from the large bevil wheels at the bottom to the top of the building. These shafts communicate with the horizontal shafts in each room, which give motion by means of straps and pulleys to every description of machinery contained in the building.

By the same process of transmission, motion is communicated—first, by an underground shaft, H, to the looms in the weaving-sheds; secondly, by an upright; again by the main horizontal shaft; and subsequently to all the light horizontal shafting in the room. In a well-organised and well-conducted establishment, the whole of the shafting is polished and kept bright. The main-shafts are composed of cast, the lighter kind of wrought-iron; and the extent of shafting kept in motion in a modern mill of this kind is about 3200 yards, or nearly two miles. From the above description, the reader may form a tolerably accurate idea of the extent and importance of a cotton-factory of modern construction, the original cost of which is about £90,000 to £100,000, and the amount of capital necessary to conduct the business not less than £50,000 more.

Of the machinery of a cotton-mill, little can be said without going into descriptive detail. We have already noticed that it is almost entirely composed of iron; and that circumstance alone may be sufficient to give it a place along with the steam-engine and millwork, as one of the constructions to which iron is applied; and a few remarks on the self-acting mule—one of the most ingenious and productive machines in this marvellous manufacture—may not be out of place. It is entirely formed of iron, excepting only the travelling-carriage, which for lightness is composed partly of wood and partly of iron. The same may be said of all the other machines, such as the winding, carding, drawing, roving, &c., which constitute the series for spinning cotton yarn, as also the sizing, dressing, and weaving machines for converting that yarn into cloth. All these machines would be of little value but for the facilities afforded in their construction by the use of iron. As respects the self-acting mule, it is a substitute for a similar machine which was formerly

worked by hand; and in the spinning of fine numbers the hand-mule is still in use, the self-actor not having as yet reached such perfection as entirely to dispense with manual labour. In the self-acting mule the *stretch*, which is about five feet, is performed by the moving power; while the backing off, the return of the carriage, and the winding on of the yarn, succeed each other without any interruption by the disengagement of the different parts of the mechanism performed by the machine itself. These are effected with great precision, so that the attendants have nothing to do but to watch its movements, to piece the broken threads when the carriage begins to move and recede from the roller-beam, and to stop it whenever the cop is completely formed, as indicated by the bell of the counter attached to the working gear.

Such are the properties of the mule, or machine for spinning yarn; and the same may be said of all the other machines which in every stage of that important branch may be considered automaton or self-acting. We could multiply instances of the same construction in the other branches of the manufacture of the textile fabrics—namely, the flax, wool, and silk; but as these observations apply more directly to the material of which the machinery in those manufactures is composed, the above will probably suffice to show that all similar machines, if properly constructed, must be made of iron.

Other machinery in similar buildings is in operation for bleaching, dyeing, printing, and finishing cotton goods. These machines, with some few exceptions, are also composed of iron; and we may attribute their present perfection and extended application to the use of this material. These facts are peculiarly interesting in regard to the application of iron to particular arts; but are comparatively unimportant when we examine its application to the manufacture of the machinery of tools. These are the parents of all other machines; and it is difficult to determine whether the skill and ingenuity displayed in their construction, or the facility with which iron adapts itself by casting, forging, and planing, to every requirement in the construction of other machines, are most to be admired. These machines possess an almost creative power: one set of good self-acting machine tools will make all other machines; and these again will produce, until the numbers are multiplied to an immense extent, each of which, for exactitude in action, is without a parallel in the past history of mechanical science. Hence it is that iron is so much in demand, and so widely extended in its application to the industrial and useful arts.

It would be easy to extend these remarks to other branches of industry, in which machinery is used and iron applied; but having given examples of its early application to corn and cotton mills, and the present construction of machinery, it will not be necessary to multiply examples in other departments of manufacture, such as those of flax, wool, and alpaca. These will all be dwelt upon in the subsequent volumes of this work devoted to the textile fabrics. It may not, however, be out of place to mention the manufacture of flax machinery, as carried on by Mr. Peter Fairbairn of Leeds, in order to point out the importance of a branch of manufacture that has recently made such rapid strides from a comparatively rude state to one of high importance:

we may mention, that in this establishment, 1000 hands or upwards are employed in the manufacture of tools and machinery; into the construction of which both iron and brass largely enter. The parts of these machines are prepared and fitted by the machine tools of which we have spoken, with a degree of accuracy seldom, if ever, surpassed.

The *heckling*, *spinning*, *roving*, and *screw-gill* machines are exquisitely made, and the boring, planing, and grooving tools, work with such precision, as to render each succeeding machine, and each part of it, a facsimile of its predecessor. The same may be said of the other tools, nearly the whole of which are self-acting, and command a power of production which few, if any, other establishment can boast of.

Water-Wheels.—We might enlarge on the merits of these machines; but having in this section already exceeded our limits, we shall conclude with an account of one of the earliest of the applications of iron, viz. to water-wheels. These are machines for receiving the motive power of a stream of water, and converting it into a uniform rotary motion, so that it may be applied to driving other machinery. Previously to the commencement of the present century, the whole, or nearly the whole of our water-wheels were made of wood; and it was reserved for the late Thomas Cheek Hewes, millwright and machinist of Manchester, to introduce an entirely new system on the principle of suspension, constructed of malleable and cast-iron, with slender wrought-iron arms supporting the rim and buckets of the water-wheel. Some affirm that this principle was first applied in

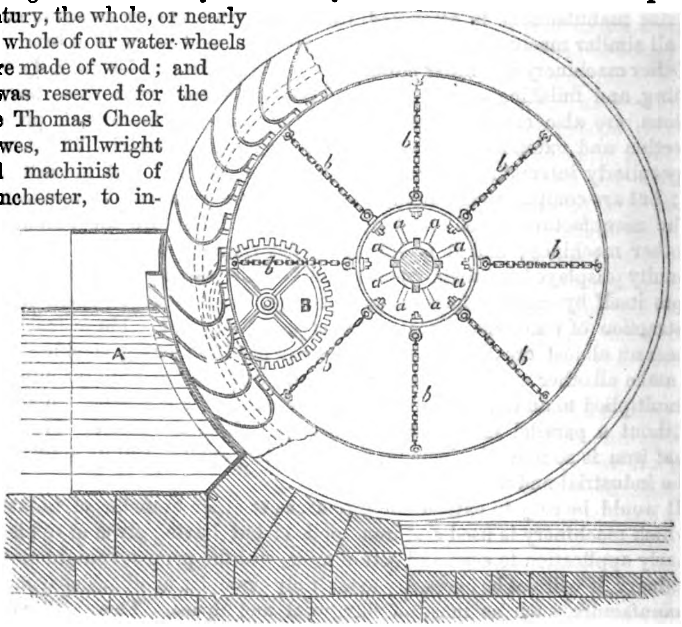


Fig. 12.

Ireland, and that the buckets of the wheel were there hung by chains kept tight by screws, as shown in Fig. 12. By this arrangement the circumference of the wheel was kept in position by the chains *b b b*, and screws *a a a*, &c. In this illustration, exhibiting radial chains, we have selected one of Mr. Fairbairn's water-wheels with ventilated buckets, adapted to low falls, as shown at A, with the pinion B working into segments on the loaded side of the wheel.

In this construction it will be observed that, so long as the chains were unyielding and retained sufficient tension to prevent the rim separating at the joints, the wheel would move; and in order to prevent the chains warping round the shaft, the motion was taken from the water or loaded side of the wheel, by the pinion B working into the segments of the shrouds; this arrangement removed the torsion and the load from the axle, and placed the weight upon the teeth of the pinion, where it was required to turn the mill. This principle of construction is admirably adapted for the transmission of power from water-wheels, and is as true in theory as it is sound in practice; but the chains, according to report, acted very imperfectly; thus, when starting one morning, the axle obstinately resisted all efforts on the part of the chains to put it in motion, and the result was the winding of the arms and braces round the shaft, and hence the partial destruction of the wheel. Mr. Hewes, however, remedied this defect by substituting (we believe at the instance of Mr. Strutt of Belper, the father of the present Lord Belper) round iron bars for the chains, which effectually met the evil, and introduced a new system of construction, which has held its ground up to the present time.

Fig. 13.

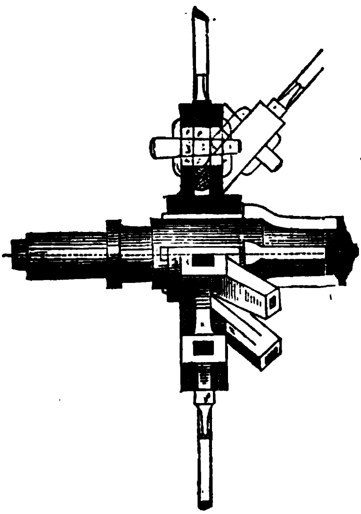


Fig. 13.*

The arms of the water-wheels constructed by Mr. Hewes were fastened with screws at each end of the axle to the flange of the centre (Fig. 13); but as these were liable to work loose, Mr. Fairbairn introduced the gibb and cotter system (Fig. 13*), inserting the arms and braces in sockets, which stiffens the beams, and retains them more effectually in position. This arrangement is a great improvement on the screws and nuts, as the gibbs and cotters are less liable to get loose, prevent vibration, and retain the arms and braces in a uniform state of tension.

Up to the year 1810, water-wheels were composed partly of wood and

partly of iron; and the late Mr. Rennie and Mr. Hewes were the first to make them entirely of iron; the axles, centres, and shrouds being composed of cast, and the arms, buckets, and sole of wrought-iron.

The next important improvement in water-wheels was the introduction, in 1827, of Mr. Fairbairn's ventilated buckets; but as these improvements do not involve the question of the application of iron, we must refer the reader to the Transactions of the Institution of Civil Engineers for a description of this improvement.

It will not be necessary to extend this part of the subject further; but we conclude with an example of four wrought-iron water-wheels, designed for Messrs. James Finlay & Co., at their works at Catrine, Ayrshire, in 1826-7.

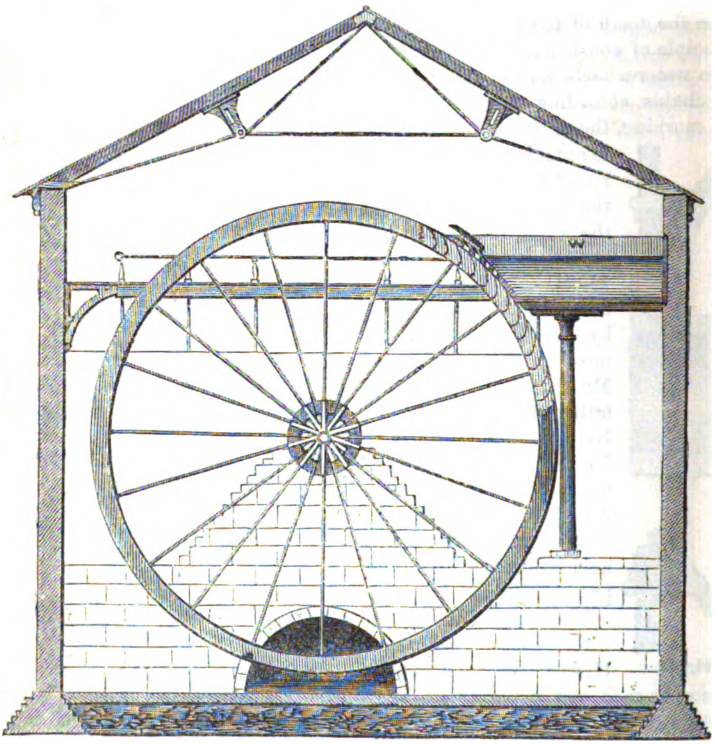


Fig. 14.—Elevation.

Figs. 14 and 15 show the arrangement of the different parts of these wheels, which, for power and dimensions, are probably the largest and most important hydraulic machines in Europe. The masonry, millwork, &c., were prepared for four wheels, but two only were erected. Each wheel is fifty feet in

diameter and twelve feet in width. The water, W, flows upon them at a height of forty-eight feet; and after having passed through the buckets, is discharged into a tunnel of eighteen to twenty feet wide, which passes under the wheels, and is ultimately discharged into the river Ayr, at a distance of a quarter of a mile below the mills. The wheels are mounted upon massive stone platforms, A A, at a height of forty feet above the spectator, who experiences a dizzy sensation as the eye follows their gigantic forms revolving round their respective centres.

The power from these wheels, it will be observed, is given off to two pinions, B B, on a connecting-shaft, and from this again to the large

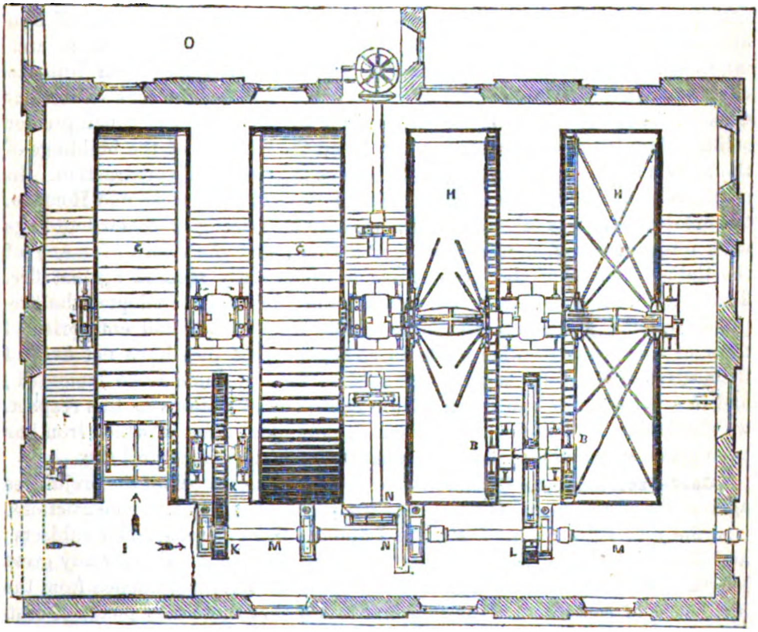


Fig. 15.—Plan.

spur-wheels, K K, L L, by which it is conveyed to the horizontal shafts M M and N N, and by these again direct to the mills, which stand at right angles to each other on two sides of the wheel-house; at I is seen part of the sheet-iron pen-trough which conveys the water to the wheels. These wheels, from their immense size, great strength and power (the two already erected being of 240 horse-power), are, as works of art, probably as good examples of the application of iron to water-wheels as are to be found in this or any other country.

CHAPTER XXI.

ON THE APPLICATION OF CAST AND WROUGHT-IRON TO ARCHITECTURE AND BUILDING.

SECTION I.—ON BEAMS.

ARCHITECTS are slow to introduce new materials of construction; and it was with some difficulty that those prejudices which prevented the use of iron and stone, or iron and brick, in combination, were overcome, notwithstanding their manifest advantages over the imperfect materials of our hitherto dangerous and perishable constructions. The public buildings of ancient Greece and Rome were erected on sounder principles and of much greater solidity than those of the present day; and the remains of the buildings of the middle ages are not without their lessons in the art of construction. In all these edifices, and also in the dwelling-houses of the Greeks and Romans, the greatest care was taken to ensure security and strength. Their buildings were often constructed with fire-proof arches; and the floors of many of the Italian houses of the present day are effectually secured against fire. The French, also, and many of the German architects, have adopted the fire-proof system; and it reflects unfavourably on the skill and enterprise of those of this country—where iron is so cheap—that they have not availed themselves of the great security it affords. This is much to be lamented; and in order to show how much we are behind other nations in this respect, we shall take in review some of the most prominent cases in which iron has been successfully employed in the constructive and architectural arts.

Cast-Iron Beams.—Smeaton was one of the first to combat the prejudices against the employment of iron. He says, speaking of cast-iron constructions, "In the year 1755, for the first time I applied them as totally new subjects; and the cry then was, that if the strongest timbers are not able for any great length of time to resist the action of the powers, what must happen from the brittleness of cast-iron? It is sufficient to say that those very pieces of cast-iron not only are still at work, but that the good effect has, in the north of England, where first applied, drawn iron into common use; and I never heard of one failing." Such were the views of one of our most distinguished engineers eighty years ago; but such has been the slowness of its application, that we hear no more of cast-iron as a building material until the year 1801, when Messrs. Phillips and Lee, of Manchester, built a fire-proof mill. The designs for the columns and beams were executed by Messrs. Boulton and Watt. The annexed figure (Fig. 16) exhibits the section of the beams, through the middle at the deepest point.

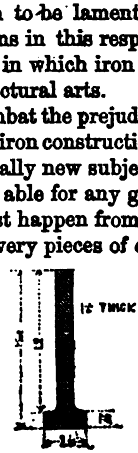


Fig. 16.—Whole area 19·06 in.: bottom flange 4·06.

This beam was the first of the kind made; and considering the state of our knowledge at that time, it reflects great credit upon the skill of the designer. If we apply Mr. Hodgkinson's rule to it, in the absence of experiment, we shall find that it approximates with tolerable correctness to the true principle, so as to secure the maximum of strength with a given quantity of material.

If we take the area of the bottom flange to be 4·06 inches, the depth of the beam in the middle $13\frac{1}{4}$ inches, and the distance between the supports 14 feet, then, by formula, 26 being the constant, we have

$$W = \frac{26 \times 4{\cdot}06 \times 13{\cdot}25}{168} = 8{\cdot}32 \text{ tons}$$

Fig. 17.

= the breaking-weight in the middle. But assuming that the same quantity of metal was run into the form of the greatest strength, we shall then have an area for the bottom flange of 7·5 inches, which gives—

$$W = \frac{26 \times 7{\cdot}5 \times 13{\cdot}25}{168} = 15{\cdot}3 \text{ tons};$$

that is, a breaking-weight nearly double that of the original beam. It is probable, however, that Messrs. Boulton and Watt's beam would carry upwards of ten tons, owing to the greatly increased thickness of the vertical part of the beam, which, it will be observed, is nearly double that of a beam of maximum strength.

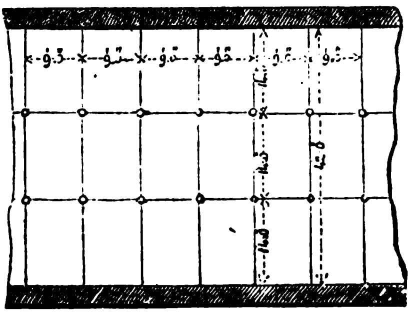


Fig. 18.—Plan.

Messrs. Phillips and Lee's mill is a large building of about 140 feet long and 42 feet wide, and seven stories high. It contains about 648 yards on each floor; and the iron beams, which extend across the building from wall to wall, at regular distances of nine feet, are divided into three lengths (A, B and C), as shown on the plan and section (Figs. 18 and 19).

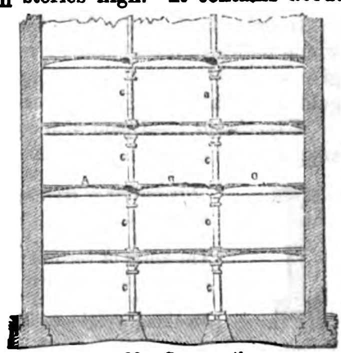


Fig. 19.—Cross section.

The following woodcut (Fig. 20) exhibits a longitudinal section of portions of the basement and first stories of the mill, with sections of the iron beams and arches. The arches E E E are nine inches in depth at the springing, seven and a quarter at a short distance on each side, and half a brick, or four inches and a half, in the middle. Altogether the experiment—considering the con-

struction of such buildings at the time—was eminently successful, and became the pioneer of that system of fire-proof structures which now distinguishes the manufacturing districts of this country.

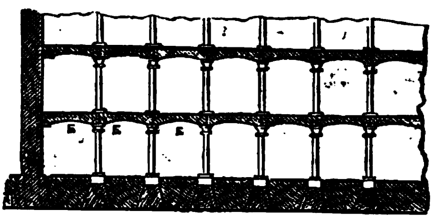


Fig. 20.—Longitudinal Section.

From 1801 till 1824 little or no variation took place in the form of cast-iron beams; and for a quarter of a century Messrs. Phillips and Lee's mill afforded the only model for similar buildings. In 1824-5 Mr. Fairbairn directed his attention to this subject, and both increased the dimensions of the lower flange and reduced the thickness of the vertical rib (Fig. 21), which gave considerable increased strength on a span of fourteen feet.

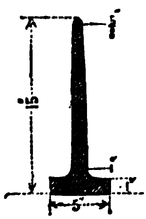


Fig. 21.

It was, however, reserved for Professor Hodgkinson to give to the world the best form for cast-iron beams; and as his deductions apply to every description of beam composed of cast-iron, it will be necessary to show how he discovered it, and to recommend it to the attention of the architect, engineer, and builder.

Mr. Hodgkinson commenced his experiments in the year 1827, and continued them without intermission for a long series of years. Mr. Tredgold published about the same time, or a few years previously, some experiments, from which he deduced a cast-iron beam of the form shown in Fig. 22. This beam was considered for many years that of greatest strength, until the experiments which follow proved it to be disproportionate, as regards the distribution of material, and hence to be comparatively weak when compared with a beam of the section of greatest strength.

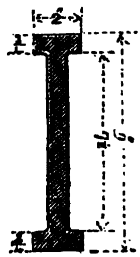


Fig. 22.

In order to show the difference, and point out the section which indicates the greatest strength, it will be necessary to give some of the most interesting of the experiments of Tredgold, Fairbairn, and Hodgkinson, as follows :—

Experiment 1.—Beam with equal rib at top and bottom. Distance between supports, 4 feet 6 inches; depth of beam, 5½ inches.

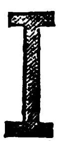


Fig. 23.

Dimensions of cross section at place of fracture in inches and parts.

Area of top rib	1·75 × ·42 = ·735
Area of bottom rib	1·77 × ·39 = ·690
Thickness of vertical part between ribs	= ·29
Area of above section	= 2·82
Weight of casting	= 36¼ lbs.
Breaking weight = 6678 lbs. = 59 cwt. 70 lbs.	

The form of fracture is represented by the line B N R (Fig. 24), where T R = ·6 and B N = 2·5, the figure being a side view of the beam.

To find the strength per sq. in. of the cross section, we have, dividing the breaking weight by the area,

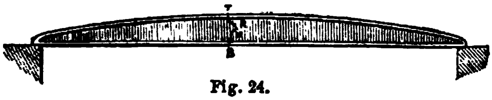


Fig. 24.

$\frac{6678}{2 \cdot 82} = 2368$ lbs. per inch. As this quantity in each beam may be taken as an index of its strength, we shall use it to compare the strength of those beams which are of the same length and depth. By the formula obtained from the experiments on the proper form for the Menai Bridge—

$$W = \frac{AdC}{l} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 1$$

where A is put for the area of the section of the material in square inches, d the depth in linear inches, l the distance between the points of support in linear inches, and C a constant, determined by experiment for the particular form of the tube. Hence we find—

$$C = \frac{Wl}{Ad} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 2$$

The value of C, determined for different forms of beams, gives us their comparative strength.

Now, for beams of the same length and depth, we have—

$$C = \frac{W}{A} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad 3$$

that is, the comparative strength of beams of this description is found by dividing their breaking-weight by their sectional area.

Hence, comparing the result of this experiment with that of Experiment 2, where the beam bore 2584 lbs. per inch, we find $2584 - 2368 = 216$ = defect;

$\therefore$ loss in strength $= \frac{216}{2584} = \cdot 083$, or 1-12th nearly, in parts of what Mr. Fairbairn's beam bore.

This form of beam is essentially what Mr. Tredgold has represented to be that of the strongest beam, whilst the elasticity is perfect. The following experiments will sufficiently show that this is not strictly true.

Experiment 2.—Beam cast in common form from Messrs. Fairbairn and Lillie's model.

Distance between supports and depth of the beam as before.

Dimensions of section in inches.

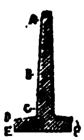


Fig. 25.

Thickness at	A =	·32
,,	B =	·44
,,	C =	·47
,,	F E =	2·27
,,	D E =	·52
Area of section	=	3·2
Weight of casting	=	40½ lbs.
Deflection with 5758 lbs.	=	·25 inches.
,, ,, 7138 lbs.	=	·37 ,,
Breaking weight	=	8270 lbs.

The beam twisted a little before breaking; this was not usually the case in the other beams from the same model.

Form of fracture as in Fig. 26: TR = ·75.

Hence, strength per inch of section $= \frac{8270}{3 \cdot 2} = 2584$ lbs.

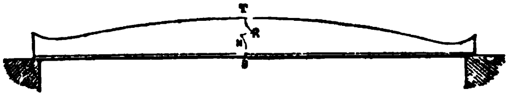


Fig. 26.

Experiment 3.—Distance between supports and depth of the beam as before.

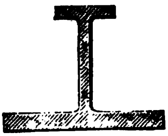


Fig. 27.

Dimensions of cross section in inches.

Area of top rib	$= 2{\cdot}33 \times {\cdot}31 =$	·72
Area of bottom rib . . .	$= 6{\cdot}67 \times {\cdot}66 =$	4·4
Thickness of vertical part	=	·266
Area of section	=	6·4
Weight of beam	=	71 lbs.

This beam broke in the middle by compression with 26,084 lbs., or 11 tons 13 cwt., a wedge separating from its upper side. The weights were laid on gradually, and the beam had borne within a little of its breaking-weight a considerable time, perhaps half an hour. The form of the fracture and wedge is represented in Fig. 28, showing a side view of the beam, where ENF is the wedge, EF = 5·1 inches, TN = 3·9 inches, angle ENF at the vertex = 82°.

It is extremely probable, from this fracture, that the neutral axis was at N, the vertex of the wedge, and therefore at three-fourths of the depth of the beam, since 3·9 inches = $\frac{3}{4} \times 5\frac{1}{4}$ inches nearly.

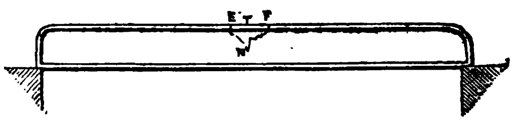


Fig. 28.

Hence, strength per inch of section $= \frac{26084}{6 \cdot 4} = 4075$ lbs., which is much greater than that in any of the former experiments.

Experiment 4.—Beam from the same model as in the last experiment. Distance between supports as before. It broke in the middle of the beam by tension, with 23,249 lbs., or 10 tons 8 cwt. nearly.

This is considerably less than what the former beam bore, though its bottom rib, in which the tensile power of this form of section almost wholly lies, was not much different. The iron must therefore have been weaker.

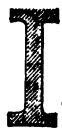
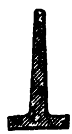
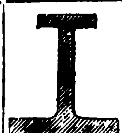
Strength per square inch of section $= \frac{23249}{6 \cdot 5} = 3576$ lbs.

Adopting Mr. Hodgkinson's calculations in the following table, we have the value of the different sections of beams experimented on by Tredgold, Fairbairn, and Hodgkinson, as the numbers 236, 288, and 382; or, taking Mr. Hodgkinson's section of greatest strength as unity, the ratios will stand—

For Hodgkinson and Fairbairn as 1 : ·754
For Hodgkinson and Tredgold as 1 : ·619
For Fairbairn and Tredgold as 1 : ·820

These numbers appear to give the relative strength of the different beams, and no doubt they had the strongest sections of all beams in use at the respective dates. It is to be regretted that we are not in possession of any comparative experiments on the beam of Boulton and Watt's section. By a simple calculation, however, we find the ratio of strength to be as 1 : ·543; that is to say, the resisting power of one of these beams, was little more than one-half that of Mr. Hodgkinson's strongest section.

Table of Results indicated by Tredgold, Fairbairn, and Hodgkinson's beams.

Weight of beam in lbs.	Distance between supports.	Area of section in inches.	Deflection in inches.	Breaking weight in lbs.	Strength per square in. of section.	Remarks.
	ft. ins.					
36½	4 6	2·82	..	6678	2368	 Fig. 29. Tredgold's section of equal flanges top and bottom.
40½	4 6	3·20	·43	8270	2584	 Fig. 30 Fairbairn's section of 1825, with a single flange.
38	4 6	2·98	·63	9503	3188	
Mean	4 6	3·13	·53	8886	2886	
71	4 6	6·4	·56	26084	4075	 Fig. 31. Hodgkinson's section of greatest strength, with area of flanges as 6 to 1.
74¾	4 6	6·5	·50	23249	3576	
Mean	4 6	6·45	·53	24666	3825	

The increased demand for fire-proof buildings, taken in connection with the attainment of the strongest section for cast-iron beams, gave a renewed impulse to their application in every direction. The beams of the form introduced by Messrs. Fairbairn and Lillie with the single flange, and those by Tredgold with equal flanges, were discarded, in order to make way for those of the improved section; and the confidence of engineers in the security of iron beams was so much strengthened, that the span, or the distance between

the supporting columns of fire-proof buildings, was increased from 14 to 20 feet. This power of enlargement occurred most opportunely, as the amplification, or rather the longitudinal extension, of some of the principal machinery in cotton mills at that particular period, necessitated a considerable increase in the width of the mills. Such, moreover, was the confidence inspired by this improved section, that buildings have been constructed from six to seven stories in height, and 52 feet wide, with only one row of pillars down the centre of each room, and two beams across, each 26 feet span between the centre columns and the walls on each side.

In the construction of the floors of warehouses which have to support heavy weights, this section of beam (when made sufficiently strong) has been found perfectly secure; and in bridges also, where the span does not exceed 50 feet, it may be used with perfect safety, if proper precautions are taken to insure sound and perfect castings.

On one occasion, and we believe only one, a girder bridge has been erected with beams 76 feet span all in one casting. They were made in this country for Messrs. John Dixon and Co., of Amsterdam, and were erected by those gentlemen on some part of the Haarlem railway.

Notwithstanding the increased security which has been gained by these improvements in the form of cast iron beams, their use is nevertheless attended with danger when either the design or construction is confided to the hands of ignorant persons; and the numerous and fatal accidents which have occurred at various times, and which have very naturally created in the public mind serious apprehension as to their security, have almost invariably been traced to this cause. On more than one occasion, as many as from fifteen to twenty lives have been lost by the failure of cast-iron beams in factories and buildings where numbers of people were congregated; and the aggregate loss of life and property from this cause has been very serious. One of the most alarming accidents of this kind happened at Oldham, on the 31st of October, 1844, arising from the breaking of one of the beams of a cotton factory. In this case upwards of twenty persons were buried in the ruins.

Among many other catastrophes of the same nature, may also be instanced that at Mr. Nathan Gough's mill at Salford, in 1828, where the beams were of a similar construction to those used in the building of the jail at Northfleet; and the more recent one at Mr. Gray's mill in Manchester, in 1845, a description of which was given in the same year to the Institution of Civil Engineers.

Compound or Trussed Iron Beams or Girders.—These combinations are very objectionable, and should on no account be resorted to but in cases of great necessity. If we take a cast-iron beam of the section of greatest strength, and endeavour, by means of truss-rods similar to A B C in Fig. 32, to increase its powers of resistance, we shall find that, under certain circumstances, they introduce an antagonistic force, which has an injurious influence; or that, in other words, the beam would be safer without the truss-rods than with them.

To some this may appear paradoxical; but, in order to ascertain how far the statement is entitled to credit, let us assume the flange *a*, Fig. 32, to

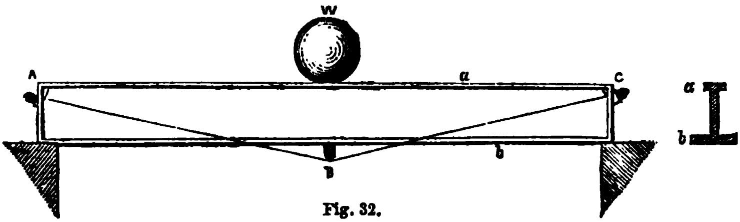


Fig. 32.

be one-sixth of the area of the flange *b*; and, under the impression of still further adding to its strength, let us suppose that two truss-rods A B, B C, are applied, one on each side of the beam, to assist in supporting the weight W.

Experimentalists having found that wrought-iron possesses great powers of resistance to extension, it became a matter of inquiry how far, and under what circumstances, cast iron and wrought-iron might be employed in the construction of beams, so as to embrace the advantages arising from these peculiar properties of the two materials. This inquiry gave rise to the construction of truss-beams, where wrought-iron is solely employed to give strength to the bottom part of the beams by its tensile resistance; while the cast-iron in the top part of the beams is solely employed to resist the force of compression. Now, if a truss-beam could be constructed so that the two materials might be brought to act in perfect concert with each other, this contrivance would, no doubt, effect a considerable economy of material; but we shall hereafter show that this is impracticable.

In a perfect truss-beam (supposing it possible to have such a thing), the cast metal should be upon the point of rupture by compression, at the same moment that the truss-rods are about to yield to extension. If too great a tension is given to the rods, they will break before the beam has arrived at the condition of rupture; on the contrary, if too small a tension is given to them, the beam will break before they have arrived at their condition of rupture. In the absence of exact data, we should say that, in order to avoid danger, the tension of the truss-rods had better be too low than too high; for, in the former case, they would yield up a portion of their tensile resistance, and then leave the remaining portion to be borne by the beam itself. An experimental trial showed the difficulty of adjusting the tension of the truss-rods, as in this case they were the first to yield to extension, and caused the beam to break with a weight which it would have nearly sustained by its own resisting powers. In order to discover the best tension for the truss-rods, it is necessary that we should consider more minutely the distinctive properties of the two metals composing a truss-beam.

The two kinds of material are very different, both in their physical and mechanical properties. *Cast-iron* is a hard, rigid, crystalline, unmalleable

substance, which presents great resistance to a force of compression, but comparatively a small resistance to that of extension; and, from its low degree of ductility, it undergoes but little elongation when acted upon by tensile force. On the contrary, *wrought-iron* is a flexible, malleable, ductile substance, which presents a great resistance to a force of extension, but a somewhat less resistance to that of compression; from its high ductility it undergoes a considerable elongation, when acted upon by a tensile force. When the two metals are released from the action of a tensile force, the *set* of the one metal differs widely from that of the other. The flexibility of wrought-iron is from eight to ten times greater than that of cast-iron. Under the same increase of temperature, the expansion of wrought-iron is considerably greater than that of cast-iron; and while wrought-iron yields to a stroke, cast-iron is readily broken by a severe collision, or by any violent vibratory action.

The following tabular generalizations of an extensive series of experiments will give an exact comparative view of these properties of cast and wrought-iron:—

TABLE I.—*Mean elongations by tensile forces within the limits requisite to rupture cast-iron, namely, about 7½ tons per square inch of the transverse section.*

Name of the metal.	Mean elongation, the force being 1 ton per sq. in.	Proportion of elongation.	Sets with 7 tons per sq. in.
Cast-iron . . .	$\frac{1}{5400}$ part of the whole length of the bar. .	$2\frac{1}{4} : 1$	$\frac{1}{7}$ of the whole elongation.
Wrought-iron. .	$\frac{1}{12800}$ part of the whole length of the bar. .		$\frac{1}{112}$ of the whole elongation.

From this table it appears that, for forces of extension below 7½ tons per square inch, the mean elongation of cast-iron is about 2¼ times that of wrought-iron. When the cast-iron is about to undergo rupture, its ultimate extension is about three times that of wrought-iron. Moreover, the set of the cast-iron within this limit is considerably greater than that of the wrought-iron.

TABLE II.—*Mean elongations and sets, with tensile forces equal to two-thirds of the forces requisite to produce rupture in each case respectively.*

Name of the metal.	Force per square inch in tons.	Elongation on 10 feet of the bar, in inches.	Proportions of elongations.	Set.	Proportions of sets.	Proportion of sets to elongations.
Cast-iron . .	5	·114	$1 : 2\frac{2}{5}$	·013	1 : 10	$\frac{1}{9}$
Wrought-iron	15	·275		·133		$\frac{1}{2}$

From this table it appears that, when the parts of a truss-beam are duly loaded, the conditions are reversed; that is to say, the elongation of the

wrought-iron becomes $2\frac{2}{5}$ times that of the cast-iron, and the set of the former becomes ten times that of the latter.

TABLE III.—*Mean values of the tensile forces requisite for producing equal elongations in cast-iron and wrought-iron bars* 10 *feet long, with the corresponding sets.*

Mean elongations on 10 feet in inches.	Cast-iron. Force per square inch in tons.	Wrought-iron. Force per square inch in tons.	Cast-iron. Set in inches.	Wrought-iron. Set in inches.
·005	·26	·56		
·024	1·11	2·5	·0012	Not perceptible.
·04	2	4·5	·0031	·0005
·05	2·5	5·6	·0043	·0007
·062	3	6·76	·0056	·0009
·087	4	9	·009	·0027
·129	5·5	12·4	·0159	·014
·145	5·9	13·26	·019	·043

This table establishes the following remarkable law, relative to the forces requisite for producing equal elongations in cast-iron and wrought-iron bars :—*Within the limit of* 6 *tons tensile strain for cast-iron and* 13½ *tons for wrought-iron, the tensile force applied to wrought-iron must be* 2¼ *times the tensile force applied to cast-iron, in order to produce equal elongations.*

This result is consistent with that of Table I., where the elongation of cast-iron, for equal increments of force, is shown to be 2¼ times that of wrought-iron. The elongations in this table may be approximately derived from Table I.

Further, with a force of about 5½ tons applied to cast-iron, and 12½ tons to wrought-iron, the sets, as well as the elongations, are nearly equal to each other. Now, if these forces had been duly apportioned to each other, this circumstance would have given us an eligible principle for adjusting the tension of the iron rods in a truss-beam: but, unfortunately, this strain upon the cast-iron is too near the strain requisite for producing rupture, while that upon the wrought-iron is only about one-half its greatest tensile resistance. For forces below 5½ and 12½ tons, the set of the cast-iron is greater than that of the wrought-iron; and for forces above 5½ and 12½ tons, the reverse takes place.

TABLE IV.—*Ultimate elongations—the cast-iron being loaded with* 7¼ *tons per square inch, and wrought-iron with* 24 *tons per square inch.*

Name of metal.	Total ultimate elongation in parts of the length of the bar.	Ultimate elongation per ton in parts of the length of the bar.
Cast-iron . . .	$\frac{1}{550}$, or ·22 in. on 10 ft.	$\frac{1}{4000}$
Wrought-iron .	$\frac{1}{21}$, or 5·7 in. on 10 ft.	$\frac{1}{520}$

Hence it follows, that the ultimate elongation of wrought iron per ton on each square inch is about eight times that of cast iron, and the total ultimate elongation of wrought-iron is about twenty-six times that of cast-iron.

If we take the results of Mr. Loyd's experiments,* where the average breaking-weight was 32 tons per square inch, we shall find that the total ultimate elongation of wrought-iron is about 130 times that of cast-iron.

TABLE V.—*Permanent set of bars, expressed in parts of their elongation.*

Weights in tons per square inch.	Cast-iron. Set in parts of the elongation.	Wrought-iron. Set in parts of the elongation.
2	$\frac{1}{13}$	Scarcely perceptible.
3	$\frac{1}{11}$	
5	$\frac{1}{6}$	$\frac{1}{110}$
7	$\frac{1}{7}$	$\frac{1}{112}$
10		$\frac{1}{80}$
15		$\frac{1}{6}$
20		$\frac{11}{13}$

Here it will be seen that, for weights below $7\frac{1}{2}$ tons, the set of cast-iron is incomparably greater than that of wrought-iron; on the contrary, for weights above 15 tons, the set of wrought iron is considerably greater than the maximum set of cast iron.

TABLE VI.—*Mean elongation of cast-iron and wrought-iron bars,* 10 *feet long, by an increase of* 90° *of temperature.*

Length of bar 10 feet.	Elongation due to 90° increase of temperature.	Difference of the elongations in 10 feet.
Cast-iron . . .	·0666 inches	·0067 inches.
Wrought-iron .	·0733 ,,	

Comparing the results of this table with those of Table I., we find that the elongation of wrought-iron, by an increase of 90° of temperature, is equivalent to the action of a tensile force of 7·4 tons per square inch; and that of cast-iron to a force of 3 tons per square inch. Moreover, the difference of the elongations is equivalent to the action of a tensile force of $\frac{3}{4}$ ton per square inch. It is also worthy of remark, that, while making experiments relative to the elongations of metals when acted upon by tensile forces, we should carefully observe that the temperature remains nearly the same.

From a careful induction of the facts contained in these Tables, let us endeavour to determine the best adjustment of the tension of the truss-rods.

FIRST, let us consider the case when the truss-rods have no strain upon them, at the time the beam is unloaded.

Suppose the beam to be loaded so as to produce a tensile strain upon the

* See the Experimental Inquiry into the Strength of Wrought-iron Plates, &c., by W. Fairbairn, published in the Transactions of the Royal Society for 1850.

cast-iron equal to one-third its breaking-load; that is to say, let the force of elongation be 2⅓ tons per square inch upon the cast metal. Then, from Table III., we find that the strain upon the truss-rods will be about 5½ tons per square inch; and that the set of the cast iron, after these strains are taken off, will be six times that of the wrought-iron. Now, in this case, while the cast-iron is strained to only about one-third its breaking-weight, the wrought-iron is strained to only about one-fifth its ultimate strength; and, further, when the load is taken off, the cast-iron beam will remain much more elongated than the iron rods, which will, to a certain extent, destroy their original adjustment of tension. But this, in the present case, will not act unfavourably; for it will tend to give a certain amount of tension to the truss-rods, considering the length of each truss-rod to be one-half the length of the beam—a supposition which obviously involves no appreciable amount of error.

Suppose the beam loaded so as to produce a tensile strain upon the cast-iron equal to 5½ tons per square inch; then, in order to produce an equal elongation of the truss-rods, the strain upon them must be 2¼ times 5½ tons, or 12⅓ tons nearly. Here, while the cast-iron is strained to more than two-thirds its ultimate resistance, the wrought-iron is only strained to about one-half its ultimate resistance. One favourable circumstance connected with this load is, that the sets of the two metals are very nearly the same.

Suppose the beam loaded so as to produce a tensile strain of 15 tons per square inch on the truss-rods; then, by Table II., this will produce an elongation of $\frac{1}{410}$th part of the length of the rod; but, by Table IV., the ultimate elongation of cast-iron is $\frac{1}{560}$th part of its length: therefore the cast-iron would be ruptured by extension, some time before the truss-rods could arrive at a strain of 15 tons per square inch; that is, before they could be strained to two-thirds of their ultimate strength.

This adjustment is defective; the truss-rods must obviously have a certain amount of tension before the load is laid on, in order to bring them into a higher condition of action, and to counteract the set of the cast metal.

Second: Suppose the truss-rods to be screwed up so as to give them a tension of 8 tons per square inch, or one third their breaking tension; and, for the sake of simplicity, let us suppose that the half-length of the beam is 10 feet. This high tension of the truss-rods, it should be observed, will produce a dangerous action upon the cast metal.

Suppose the beam to be loaded so as to produce a tensile strain of 7⅓ tons per square inch upon the cast metal. Now, by Table IV., this would give an elongation of ·22 inches; but the truss had an elongation of ·077 inches due to the strain of 8 tons when the beam was in a neutral condition; therefore the total elongation of the truss-rod will be ·22 + ·077, or ·297 inches; but from Table II. we find this elongation to correspond to about 16 tons per square inch tensile force upon the rods. Thus it appears that even with the dangerous tension of 8 tons per square inch on the truss-rods, we cannot produce a higher strain than 16 tons upon them at the moment when the cast-iron is about to rupture.

Reasoning in this manner, it may be shown that it is impossible to construct a truss-beam which shall task the high tensile resistance of wrought-iron, without, at the same time, introducing a dangerous action upon the cast metal. We have shown, in Tables II. and IV., that for high proportional tensions the rate of elongation of wrought-iron is from ten to twenty-six times that of cast-iron: hence it is impossible to have the two metals acting in concert at tensions approaching their rupture.

Since little is gained by this high tension in point of ultimate strength, and much is lost by the injury done to the beam, we must reduce this tension in order to arrive at the best form of the truss-beam.

THIRD: Let us endeavour to discover the tension which must be given to the truss-rods, so that the different parts of the truss-beam may be respectively loaded, at the same moment, with one-third their respective ultimate tensile resistances, viz. $2\frac{1}{3}$ tons per square inch for the cast-iron, and 8 tons per square inch for the wrought-iron.

Here, by law of Table III., the additional force tending to elongate the iron rods per square inch $= 2\frac{1}{4} \times 2\frac{1}{2} = 5\frac{5}{8}$ tons. Putting $t =$ the tension of the rods per square inch at the moment when the cast metal has no strain upon it, we have—

$$t + 5\tfrac{5}{8} = 8;$$

$$\therefore\ t = 2\tfrac{3}{8} \text{ tons per square inch, or } 2\tfrac{1}{2} \text{ tons nearly.}$$

Suppose the beam to be loaded so as to produce a tensile strain of 4 tons per square inch of the cast metal, then the truss-rods will undergo an additional strain of $2\frac{1}{4}$ times 4 tons, or 9 tons per square inch, which, added to $2\frac{1}{2}$ tons, will give $11\frac{1}{2}$ tons for the whole strain per square inch of the truss-rods; so that the two materials will be loaded to about one-half their respective breaking-weights; and, moreover, it may be shown from Table III that the sets of the two metals, after the load is taken off, will be nearly the same.

Hence it appears that the most eligible adjustment of the truss-rods is to give them a tension of from 2 to 3 tons per square inch.

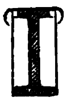
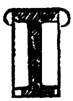
But a load of $5\frac{1}{2}$ tons per square inch on the cast metal would tend to destroy the adjustment; for this would produce a strain of about $13\frac{1}{2}$ tons per square inch on the truss-rods; and after the load is taken off, the set of the wrought-iron would be about three times that of the cast metal. It may be further observed, that a strain of less than 15 tons upon the wrought-iron would rupture the cast metal.

An ordinary beam, especially when the material is wrought-iron, may be safely loaded, to meet contingencies or particular exigencies, within two-thirds of its breaking-load. But this cannot be done with truss-beams; for, with the best adjustment of the trusses, as we have shown, the cast metal will be upon the point of rupture before the wrought-iron has attained two-thirds of its ultimate resistance.

Upon the whole, it appears to be impracticable to attain such an adjustment of the parts of a truss-beam as to secure the safety of the beam, with a due regard to the most efficient action of all its parts. The two

materials are so different in their physical, as well as in their mechanical, properties, that it seems impossible to construct a beam with them where they can, under all ordinary strains, act in concert with each other. The effects of truss-rods on the different descriptions of beams are noted in the following

Summary of Results of Experiments.

Sketch of beam.	Description of beam.	Breaking-weight in lbs.	Ratio of strength in lbs.
	Cast-iron beam, with the broad flange downwards	5380	100 : 127
	The same beam in the same position, with double truss-rods supporting the middle	7433	
	Beam reversed; the broad flange uppermost, without truss-rods	3366	100 : 333
	The same in the same position, with broad flange supported by truss-rods .	12,316	
	Beam with double truss as before, broad flange below	7433	100 : 165
	The same, with double truss; broad flange uppermost	12,316	
	Beam, without truss-rods; broad flange uppermost	3366	100 : 173
	The same beam, broad flange downwards	5830	

From the above summary we may draw the following conclusions:—1st.

That the advantage gained by truss-rods to a cast-iron beam of the strongest section, and placed in the best position for resisting a transverse strain, is as 100 : 127, being rather more than one-fourth of increase in strength. 2nd. That the simple beam reversed with the small flange downwards loses above one-half of its strength, as compared with the same beam in its most favourable position, with the large flange downwards, or as 100 : 173. Again, let the beam be reversed and trussed, with the small flange downwards, and its resisting powers are increased 3⅓ times in strength as compared with the same beam in the same position without the trusses, or as 100 : 333. Lastly, that the same beam, being trussed in both instances, first with the broad flange downwards, and subsequently with the broad flange upwards, gains nearly three-fourths in strength in the latter case; while the other is not materially increased beyond that of the simple beam entirely free from auxiliary support.

But even supposing that we are able to construct a truss-beam with all its particular parts perfectly adjusted, how long would it remain so? Besides the disturbances arising from unequal elongations and sets, sudden collisions, changes of temperature, and other causes, would tend to destroy this adjustment. The defect of a truss-beam consists not so much, perhaps, in its want of economy as regards the distribution of material, as in its want of stability and safety. Within comparatively small limits of load, a truss-beam may pass from a condition of perfect security and safety to one of uncertainty and danger.

We might multiply these comparisons to a much greater extent; but we have done sufficient to prove the fact, that, under the most favourable circumstances, there is not much gained in the strength of cast-iron beams by the addition of malleable iron truss-rods. When such auxiliaries become absolutely necessary, we would then recommend them to be attached to beams, with a strong flange on the upper side to resist compression, and the tension-rods so regulated and proportioned in strength as to cause them to act simultaneously with the rigid top in their resistance to fracture. What is, however, infinitely preferable, is a well-constructed malleable iron beam, which may be made of almost any given strength, and of any span within the limits of 500 to 1000 feet.

Approximate Rule for Calculating the Strength of a Truss-beam.

In order to calculate the strength of trussed beams, let us suppose that the tension of the rods is such as to cause them to have a strain of 8 tons per square inch, at the same moment that the cast-iron has a strain of 2½ tons per square inch: then, with this *perfect adjustment*, we have found, by a process of reasoning which need not be given in this place, the following approximate rule for calculating the weight with which the beam may be safely loaded:—*Add three times the section of the truss-rods to the section of the bottom flange, substitute this sum for the bottom area in the usual formula for calculating the strength of cast-iron beams, and one-third this result will give the weight of safety, or one-third the theoretical breaking-weight.*

Thus, let $w =$ the load of safety, $a =$ the area of the bottom flange, $a_1 =$ the section of the truss-rods, $l =$ the distance between the points of support, and $d =$ the depth of the cast-metal beam; then

$$w = \frac{26\,(a + 3a_1)\,d}{3l} \text{ tons} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

In one of a series of experiments, we find $a = 1{\cdot}05$, $a_1 = {\cdot}39$, $d = 4$, $l = 4{\cdot}5 \times 12$;

$$\therefore\ w = \frac{26\,(1{\cdot}05 + 3 \times {\cdot}39)\,4}{3 \times 4{\cdot}5 \times 12} = 1{\cdot}4 \text{ tons} = 3100 \text{ lbs nearly.}$$

Now the breaking-weight of this beam was nearly 9000 lbs., giving one-third of 9000 lbs. = 3000 lbs. for the load of safety. Hence it appears that in this truss-beam we had very nearly hit upon a perfect adjustment.

Throughout these calculations we have assumed that the section of the top flange of the beam is duly calculated to balance the united tensile forces of the truss-rods and the bottom flange of the beam.

Let us now consider the question of economy as regards these beams.

Comparison of Cost.—In estimating the comparative advantages of different forms of beams, we should always consider their ratio of cost for a given amount of strength. In order to apply this method of comparison to the case of trussed beams, let $a =$ the cost of the beam without the trusses, $a_1 =$ the cost of the truss rods, $a_2 =$ the cost of their construction, $w =$ the breaking-weight of the beam without the trusses, and W the breaking-weight with the trusses; then we have—

Comparative advantage of the trussed beam, the beam without the trusses being represented by unity,

$$= \frac{a}{a + a_1 + a_2} \times \frac{W}{w} \quad . \quad . \quad . \quad . \quad (1.)$$

In the case of one of the beams experimented upon, for example, we have—

$$a = 4\tfrac{1}{2} \text{ shillings, } a_1 + a_2 = 4 \text{ shillings, } w = 5800, \ W + 7400;$$

then by formula (1) we have—Comparative advantage of the trussed beam,

$$= \frac{4\frac{1}{2}}{4\frac{1}{2} + 4} \times \frac{7400}{5800} = \tfrac{2}{3} \text{ nearly;}$$

that is to say, the advantage of the simple beam as compared with the trussed beam, is nearly as 1 to $\frac{2}{3}$.

Strength of Cast-Iron.—On the resisting powers of cast-iron, some curious and interesting facts have been developed by experiments conducted some years since at the request of the British Association for the Advancement of Science, conjointly by Mr. Hodgkinson and Mr. Fairbairn. It has always been a very important question, what is the effect of lengthened time in diminishing the resisting powers of heavily-loaded structures, or whether a continuance of a force having a tendency to rupture the parts of a beam will ultimately lead to fracture. To solve this question, and to determine the law which governs the resisting powers of cast-iron under such circumstances, the following experiments were introduced. They commenced in March, 1837,

and terminated in 1842; and as these experiments materially affect formally acknowledged theories on the strength of materials, it may not be inexpedient to give the results as they were uniformly recorded during a long series of experiments.

TABLE I.—*Permanent Loads.*

Coed-Talon rectangular bars, 4 ft. 6 ins. between supports, loaded with different weights for determining the changes of deflection which take place during indefinite periods of time, the mean breaking-weight of each sort of iron having been previously ascertained to be—for the cold-blast, 508 *lbs., and for the hot-blast,* 484 *lbs.*

No. of bars.	Permanent load in lbs.	Mean breaking-weight in lbs.	Ratio of breaking-weight to load.	Remarks.
1	280	508	1 : ·551	Cold-blast iron.
2	336	508	1 : ·661	
3	392	508	1 : ·771	
4	448	508	1 : ·881	
5	448	508	1 : ·881	
6	280	484	1 : ·578	Hot-blast iron.
7	336	484	1 : ·694	
8	392	484	1 : ·805	
9	448	484	1 : ·925	
10	448	484	1 : ·925	

From the above will be seen the nature of the experiments which were instituted for the purpose of ascertaining, by an exceedingly minute scale, the increase of deflection which, from time to time, took place on the bars. If that increase were progressive, it might then be inferred that rupture must at some time or other (however remote) take place; if otherwise, that a new arrangement of the molecules of the parts under strain had taken place, and had thus become fixed with a power of resistance equivalent to the load. The results from March, 1837, till April, 1842, were as follow:—

TABLE II.—*Results on bars Nos.* 2 *and* 7, *loaded with* 336 *lbs.*

Temperature.	Date of observation.	Cold-blast deflection in inches.	Hot-blast deflection in inches.	Ratio of increase.
..	11 March, 1837	1·270	1·461	Previous to the time of taking the deflection in Nov. and April, the hot-blast bar had been disturbed.
78°	3 June, 1838	1·316	1·538	
72°	5 July, 1839	1·305	1·533	
61°	6 June, 1840	1·303	1·520	
50°	22 Nov., 1841	1·306	1·620	
58°	19 April, 1842	1·308	1·620	
53°	Mean	1·301	1·548	

The above experiments show a mean increase in the deflection of the cold-blast bar during a period of five years of ·031, and of ·087 in that of the hot-blast bar.

TABLE III.—*Results on bars Nos.* 3 *and* 8, *loaded with* 392 *lbs.*

Temperature.	Date of observation.	Cold-blast deflection in inches.	Hot-blast deflection in inches.	Remarks.
..	6 March, 1837	1·684	1·715	
78°	23 June, 1838	1·824	1·803	
72°	5 July, 1839	1·824	1·798	
61°	6 June, 1840	1·825	1·798	
50°	22 Nov., 1841	1·829	1·804	
58°	19 April, 1842	1·828	1·812	
53°	Mean.	1·802	1·788	

During five years, the increase of the deflection of the cold-blast bar has been rather more than that of the hot-blast, the mean increase being as ·118 to ·073; whereas in the former table the increase was on the other side, or as ·031 to ·087. Nevertheless, the deflections in this case indicate, as before, a steady increase of deflection.

TABLE IV.—*Results on bars Nos.* 4, 5, 9, *and* 10, *loaded with* 448 *lbs.*

Temperature.	Date of observation.	Cold-blast deflection in inches.	Hot-blast deflection in inches.	Remarks.
..	6 March, 1837	1·410	..	Both the hot-blast bars broke at once with 448 lbs., and one of the cold-blast bars broke after sustaining the weight thirty-seven days.
78°	23 June, 1838	1·457	..	
72°	5 July, 1839	1·446	..	
61°	6 June, 1840	1·445	..	
50°	22 Nov., 1841	1·449	..	
58°	19 April, 1842	1·449	..	
53°	Mean.	1·442	..	

The progressive increase in the deflection in this case is ·032; which, it will be observed, is much less than those exhibited in the former table with weights of 392 lbs., and less than the increase of deflection of the hot-blast bar in Table I.

Viewing the whole of these results in the light of a problem affecting the laws which regulate the resistance of bodies to continuous strain, it is important to know how admirably the cohesive powers of matter adapt themselves to circumstances, and with what tenacity they resist forces tending to dissever and rupture their parts. It yet becomes a question for consideration how far this power extends, and whether or not bodies, when loaded even within one-thousandth part of the weight that would break them, would or would not *sustain the load for ever*, provided no disturbing cause were present to produce fracture. Notwithstanding the fact that the whole of the loaded bars exhibit an increase of deflection, the writer is inclined to

think such would be the case, and to attribute the deflection to the vibrations continually going on in the building, and to the changes—such as temperature, oxidation, &c.—to which every description of material is subject.

In these experiments it was fully established that a continued and perfectly permanent pressure, even when approximating to fracture, is very different to the law of deflective elasticity, caused by changes affecting the conditions of material. These changes are the increase and diminution of pressure, producing a disturbing force on all the parts under strain; and by a continued series of alternations, eventually destroying the antagonistic powers of resistance.

In the former case, the load, however near it approximates to fracture, remains permanently fixed; whereas, in the latter, the changes, however minute, will, if continued long enough, lead to destruction. Mr. Hodgkinson's, as well as Mr. Fairbairn's, experiments lead to this conclusion; and we have no doubt that any load, however small, producing a permanent set upon a bar, when taken off and again restored a sufficient number of times, will at last break it. For example, suppose we take the bars supporting the lightest weights, 280 lbs., and admitting that the load be removed, or relieved to the extent of 200 lbs. every thirty seconds, it is evident that this change, often repeated, will, in the end, destroy the cohesive powers of the bar, either in the lower part of its crystalline extended section, or in the upper part where the crystals are compressed, and where it is probable the destructive process would be progressive in a given ratio. This constant movement of the atoms of crystalline as well as fibrous bodies is, probably, the cause of breakage; and however slight the strain may be when applied first in one direction and then in another, it only becomes a question of time how long it will bear these continued repetitions before rupture takes place.

TABLE V.—*Comparative Strength and Power to resist impact of the Coed-Talon hot and cold-blast iron at various temperatures.*

Transverse Strengths.

Temperature.	Coed-Talon cold-blast.	Coed-Talon hot-blast.	Ratio.
Fahrenheit.	No. 2 iron.	No. 2 iron.	
26°	851·0	823·1	1000 : 967·2
32°	{940·7, 958·5} Mean 949·6	{933·4, 906·0} Mean 919·7	1000 : 977·6
190°	743·1	823·6	
Red in dark.	723·1	829·7	1000 : 1108·0
	No. 3 iron.	No. 3 iron.	
212°	{905·0, 943·6} Mean 924·3	818·4	1000 : 885·4
600°	{909·3, 1157·0} Mean 1033·1	{834·1, 917·5} Mean 875·8	1000 : 847·7

Power to resist Impact.

Temperature.	Coed-Talon cold-blast.	Coed-Talon hot-blast.	Ratio.
Fahrenheit.	No. 2 iron.	No. 2 iron.	
26°	349·8	340·8	1000 : 974
32°	360·3, 404·5; Mean 382·4	406·9, 383·2; Mean 395·0	1000 : 1032·9
190°	223·7	298·9	1000 : 1336

Modulus of Elasticity in Pounds for a Base of one inch square.

Temperature.	Coed-Talon cold-blast.	Coed-Talon hot-blast.
Fahrenheit.	No. 2 iron.	No. 2 iron.
26°	12994400	14267500
32°	13506700, 15148200; Mean 14327450	13723500, 14283200; Mean 14003350
190°	14398600	13869500

In pursuing these investigations, it unfortunately happened that the stock of No. 2 iron became exhausted; a circumstance which intercepts the comparison from six degrees below the freezing-point of water to the temperature of melted lead.

The No. 3 should have been broken at all the points of temperature, in order to have ascertained the loss of strength as the heat increased. It was not, however, accomplished; and from this circumstance the comparison only holds good between the two qualities, No. 2 and No. 3, from the boiling point of water, or 212° up to 600° of Fahrenheit. In the No. 2 iron it will be observed that the strength continued to diminish as the temperature increased; whereas in No. 3 it increased, as shown in the table, from 924·3 to 1023·4, which can only be accounted for from the irregularity and greater rigidity of that description of iron. On the whole, we may infer that cast-iron, of average quality, loses strength when heated beyond a mean temperature of 120°; and it becomes insecure at the freezing-point, or under 32° of Fahrenheit.

On Wrought Iron Beams.—Of late years the extensive application of malleable-iron to every kind of iron construction, has led to the adoption of wrought-iron beams in place of the cast-iron and trussed beams of which we have been treating. Wrought-iron may be obtained in plates of almost any size; and these, connected together by riveting, and strengthened by angle and T irons, form the safest, strongest, and in most cases the cheapest of all constructions.

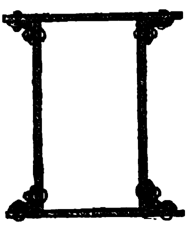


Fig. 33.

At first the box-beam, of which Fig. 33 represents a section, was considered superior to the flat beam represented in Fig. 34. These two beams have been alternately employed for the

purposes above mentioned; but we have invariably given the preference to the plate-beam (Fig. 34), on account of its simplicity of construction; although inferior in strength to the box-beam, it has, nevertheless, other valuable properties to recommend it.

Fig. 34.

On comparing the strength of these beams separately, weight for weight, it will be found that the box-beam is to the plate-beam as 1 : ·93, or nearly 100 : 90. This difference in strength does not arise from any want of proportion in the top and bottom sections of either beam, but from the position of the material, which, in the box form, offers greatly superior powers of resistance to lateral flexure. Taking the plate-beam, however, in a position similar to that in which it is used for supporting the arches of fire-proof buildings, or the roadway of a bridge where the vertical position is maintained, its strength is very nearly equal to that of the box-beam; while in such a position it is of more simple construction, less expensive, and more durable from the circumstance that the vertical plate is thicker than the side plates of the box-beam, and is, consequently, better calculated to resist those atmospheric changes which, in this climate, have so great an influence upon the durability of the metals. Besides, it admits of easy access to all its parts for the purpose of cleaning, painting, &c.

In all buildings, such as warehouses, cotton and flax-mills, and dwelling-houses which require protection from risk, whether arising from weakness, from the employment of a more dangerous material such as cast-iron, or from fire, it will be found exceedingly valuable, irrespective of the sense of security which the nature of the material is sure to establish in the public mind.

One feature in the use of this material is the scope which it gives for an extension of space to any distance commensurate with the convenience of the establishment, or the taste of the architect or engineer. Most of the improved cotton-mills are from 60 to 65 feet in width, with two or three rows of columns, at distances of 15 to 16 feet across the mill, and from 9 to 10 feet in the direction of its length. These columns present serious obstructions to the convenient arrangement and free-working of the machinery, but they cannot well be avoided where cast-iron beams are used. By the employment of wrought-iron they quickly vanish, as one row of columns with only two beams in width not only meets the objection, but removes all doubts as to the security of the structure. In these constructions, however, it must be borne in mind that an increase of space is attended with a considerable increase of expense; but when the latter is not a serious consideration, fire-proof mills might be built upwards of 60 feet in width without the introduction of a single column, or any other obstruction whatever.

In large buildings this may be effected with perfect ease, and the beams so constructed as to carry a load of 4 or 5 tons to the square yard. Let us, however, return to those erections which require a centre column, with a distance of 30 feet on each side between the bearings. In a building of this kind, the beams will each be 31 feet 6 inches long, and 30 feet between the

supports; and may be composed of plates 22 inches deep, $\frac{5}{16}$ thick, and angle-iron $\frac{1}{2}$ and $\frac{3}{8}$ths of an inch thick, rivetted on both sides, as shown in the section, Fig. 35. Taking the constant at 75, which we take instead of 80, used for computing the strength of hollow girders with cellular top, to compensate for defects in form which cannot be remedied in the single-plate girder, the breaking-weight of this beam would be as follows:—

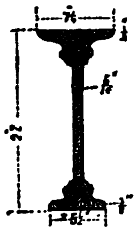


Fig. 35.

Let W represent the breaking-weight in tons, a the area of the bottom flange, d the depth of the beam $= 22$ inches, $l =$ the distance between the supports $= 360$ inches, then we have

$$W = \frac{adc}{l} = \frac{75 \times 6 \times 22}{360} = 27{\cdot}5 \text{ tons in the middle,}$$

or 55 tons distributed equally over the surface.

Now, a cast-iron beam of the best form and strongest section, and calculated to support the same load, would weigh about 2 tons; whereas the wrought-iron beam would only weigh 16 cwt. 1 qr. 14 lbs., or a little more than one-third of the weight of the cast-iron beam. This difference is of considerable importance, as there is less weight to carry, and much greater certainty as regards the ultimate strength and security of the beams. Let us, however, extend the comparison still further, and endeavour to ascertain the cost of the material and construction of each kind of beam, which, after all, is the only criterion of the utility and fitness of any improvement. Every invention resolves itself into this comparison; and, in order to secure a successful application, the superiority of the article (when other things are the same) must be measured by the price at which it can be produced.

Assuming, therefore, that cast-iron beams can be delivered at the foundry at £6 10*s.* per ton, and that the wrought-iron plate-girders can be manufactured at £16 per ton, it follows that

A cast-iron beam, 40 cwt., at 6*s.* 6*d.* . . . . £13 0*s.*
A wrought-iron beam, 16 cwt. 1 qr. 14 lbs., at 16*s.* . . . £13 2*s.*

making a difference of only two shillings between the cost of the one and the cost of the other. Assuming, therefore, the prices to be the same, we have, in the case of wrought-iron beams, only about one-third of the weight of metal to carry; while the lighter weight of the wrought-iron beams will enable us to erect and fix them in their places at considerably less cost. Altogether, we are persuaded that wrought-iron beams, manufactured on a large scale, might be supplied at a rate so moderate as to answer that most desirable object, the combination of strength with lightness and security. The writer is even of opinion that beams of this description can be manufactured at £14 per ton instead of £16, as quoted above. If this can be effected, there is a direct saving of £1 10*s.* 9*d.* per ton; a very important economical consideration, independently of the increased security.

Should this description of beam become general in its application, it is more than probable that all those under 12 cwt. might be delivered at once of the

required form from the rolling-mill; and it would be premature to assume that even the larger sizes could not be manufactured in the same manner. At the Paris Exposition in 1855, some wrought-iron beams and joists of this kind were exhibited by French manufacturers, showing a degree of perfection such as has not yet been attained in this country. Some of the joists of the sectional dimensions shown in Fig. 36 were rolled 60 feet long; and another specimen of still greater dimensions, as in Fig. 37, was rolled 40 feet long. In the manufacture of malleable-iron beams in France, sufficient attention has not been paid to sectional form in order to attain the section of greatest strength. In wrought-iron beams the area of the top flange requires to be nearly double that of the bottom, as shown in Fig. 35; but as yet this class of work has not been produced in England. If this description of beam were properly rolled and manufactured, it would effect a great saving in mechanical construction, and would, at the same time, ensure much greater uniformity and certainty in the strength of beams, avoiding altogether the system of joints and the riveted angle-iron, which constitutes our present defective mode of construction.

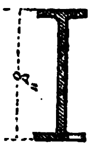


Fig. 36.

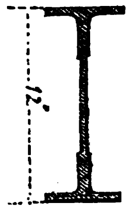


Fig. 37.

Hitherto we have treated of beams of light weight and short span; instances, however, occur where they are required of large span and considerable strength; and in recommending this peculiar application, it may be

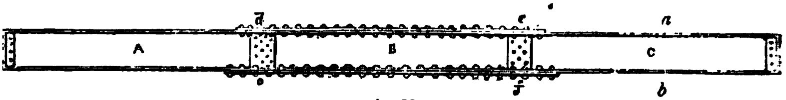


Fig. 38.

necessary that we should meet these requirements by the introduction of a construction suitable for such purposes. We have already remarked, that the smaller description of wrought-iron beams may be produced at once from the rolling-mill, at a very moderate price per ton. In cases where the extent of span required would render it impracticable to roll the beam in one piece, convenient weights might be rolled into sections of the proper form, and a beam of excellent description be constructed by joining the parts together, as shown in the annexed elevation and sections (Figs. 38, 39, and 40).


Fig. 39.

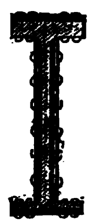


Fig. 40.

In the construction of this beam, the parts A, B and C are rolled separately to the form shown in Fig. 39, which is a section through *a b*; and being united by proper covering-plates and rivets, it will form a section at the junction through the lines *c d*, *e f*, as exhibited in Fig. 40. This construction may be applied to a span of 40 to 50 feet; and provided the covering-plates are properly proportioned and the riveting well executed, the beam

will be equal in strength to one formed of solid iron, without the intervention of a single joint.

It is probable that the rectangular box-beam is more appropriate for the support of great weights on a large span than the plate-beam recommended above; but we have already stated our objections to the box-beam, viz. the danger of oxidation, and the impossibility of reaching the interior for the purpose of cleaning, painting, &c.; and we are of opinion that, with proper care in the construction, in spans up to forty, and in some cases up to fifty feet, the plates will be found superior to any other description of beam. In cases where the distance between the supports exceeds fifty feet, the tubular girder is evidently the best form of beam; but of this we shall speak more fully when we come to treat of bridges.

SECTION II.—ON IRON FLOORS, ROOFS, &c.

Cast-Iron Columns.—Among the applications of iron, cast-iron columns will continue to hold a prominent position. The great resistance of cast-iron to compression was proved by experiments already referred to (page 391), when treating of artillery and ordnance.

The subject of columns has been ably investigated by Professor Hodgkinson, and he has deduced some interesting results from a long series of experiments. He has shown that the strength of cast-iron pillars with their ends flat, bears a constant ratio to their strength when their ends are rounded. Taking the mean results as derived from the experiments, we have the following curious facts:—

Columns.	Breaking-weights in lbs.				
Both ends rounded . . .	143	3017	7009	7009	16493
One end rounded and one flat .	256	6278	13499	13565	33577
Both ends flat or with discs .	487	9007	20310	22475	..

In the above table it will be observed, that the pillars in each vertical column are of the same length and diameter; the strengths, therefore, in the three different cases, reading downwards, are as 1, 2, 3 nearly, the middle being an arithmetical mean between the other two. It is shown, moreover, by the experiments on timber, wrought-iron, and steel, that the strength of a pillar with one end rounded and the other flat is always an arithmetical mean between the strengths of pillars of the same dimensions, with both ends rounded and both flat, however the strength of these may vary.

That the same law appears to apply to wrought-iron and timber, may be seen from the following results:—

	Length in inches.	Ends rounded.	Ends rounded and flat.	Ends flat.
Wrought-iron . .	$90\frac{3}{4}$	1808	3355	5280
Wrought-iron . .	$60\frac{1}{8}$	3938	8137	12990
Timber	$60\frac{1}{8}$	3197	6109	9625

The strengths in these cases are, therefore, as 1, 2, 3, nearly the same as those on cast-iron, the middle being an arithmetical mean between the other two. These are facts that require careful attention on the part of architects and builders, as the bearing powers of a column may be weakened one-third by having one of its ends rounded, and two-thirds when both ends are rounded. All columns should, therefore, have flat ends.

Floors.—Before entering on the application of iron to roofs and the construction of houses, churches, &c., it will be desirable to notice the French system of constructing the floors of dwelling houses and public buildings. There are two systems at present in use in the French metropolis, the *Système Vaux* and the *Système Thuasné*; the former employing flat-rolled iron joists, the latter rolled iron joists with flanges. In both systems the joists are united by transverse tie-rods, and these again are interlaced by small bars of iron, varying from three-eighths to one-half inch square, according to circumstances. These methods have been in use for some years past; but that of M. Thuasné, which is simply an improvement in the form of the joists, has come into general use since the commencement of the alterations of the Louvre and the Rue de Rivoli. The beams generally employed are similar to those shown in Figs. 36 and 37; and they vary in depth, thickness, and length, according to the width of the room or the length of the span. At first they were placed at distances of one metre apart = 3 feet $3\frac{1}{4}$ inches; but that distance was found to be inconvenient, not giving sufficient strength and rigidity to the floor; and hence they are now placed at about two feet asunder.

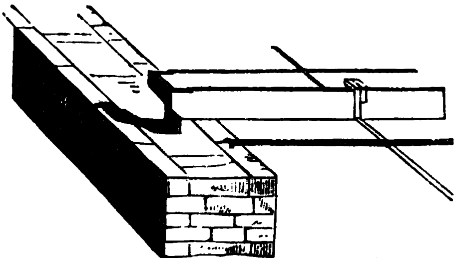
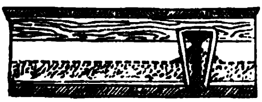


Fig. 41.—Systeme Vaux.



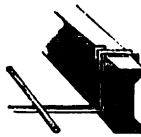


Fig. 42.—System in general use.

Fig. 43.—Systeme Thuasne.

FRENCH METHOD OF CONSTRUCTING IRON FLOORS.

The usual way of forming the ceiling, is to force upwards, against the bottom of the iron joists, flat boards, which answer as a centering, and then to fill up the spaces between the joists and tie-rods, to a depth of $2\frac{1}{2}$ or 3 inches, with a coarse grout of plaster of Paris. This hardens almost immediately, and forms a ceiling ready to receive the finishing coat of fine plaster. The upper part above the iron joists is then filled up with hollow brick or small cylinders of baked clay like flower-pots; and these being again

grouted, form an excellent bond to the iron joists. On the top of these groutings may be formed the floor, of tiles or concrete, as most convenient; or a wooden floor may be introduced, which is frequently done by embedding wooden sleepers at the required distances to receive the boarding.

M. Thuasné published, a year or two since, a table of sizes of joists and prices for the use of builders and the public, of which Mr. Burnell gave the following translation in a paper read to the Royal Institute of British Architects in 1854:—

Bearings: Ft. in. Ft. in.	Depth of joist in inches.	Depth of floor complete in inches.	Weight per square: lbs.	Iron-work per square. £ s. d.	Including grouting (12s.) per square. £ s. d.
10 0 to 11 6	4	7⅛	370	2 19 5	3 11 5
11 6 to 13 0	4¾	7⅞	420	3 6 5	3 18 5
13 0 to 16 6	5⅛	8⅝	465	3 14 4	4 6 4
16 6 to 20 0	6¼	9⅛	510	4 1 9	4 13 9
20 0 to 23 0	7⅛	10¼	605	4 17 6	5 9 6
23 0 to 26 0	8⅝	11¾	700	5 12 4	6 4 4

There is no limit to the length of riveted wrought-iron beams within sixty or even one hundred feet; but with iron joists and beams from the rolls the case is different, the limit being, with our present machinery, about thirty feet. Rooms of twenty-four and twenty-six feet have been constructed of such joists without main girders; but when the span exceeds twenty-six or thirty feet, it is probably safer to use a main central girder, and diverge with the iron joists on each side; by this means the weight will be reduced, and the span extended up to forty or fifty feet, in cases where the nature of the building requires that width.

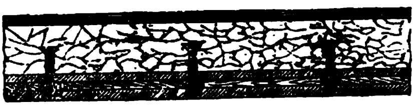


Fig. 44.

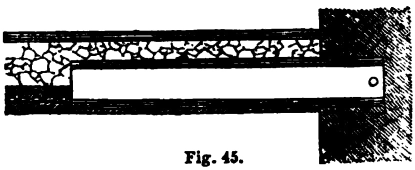


Fig. 45.

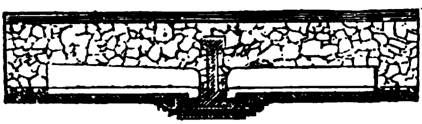


Fig. 46.

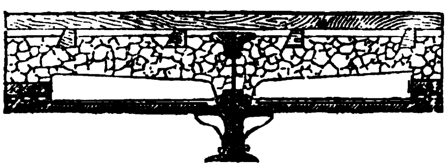


Fig. 47.

FOX AND BARRETT'S FIRE-PROOF FLOORS.

In regard to these constructions it may be added, that there is hardly any limit to which wrought-iron girders might not be carried; but it has been ascertained that the limit of a tubular girder bridge is 1800 feet span, as it has been shown that at that distance the weight of material contained

in the structure breaks the girder. In dwelling-houses and public buildings, fifty to sixty feet in width is seldom exceeded; and in such cases it is the safest and the cheapest plan to introduce main tubular girders at twenty or twenty-four feet apart, and to fill up longitudinally with rolled iron joists.

This system of applying iron to the construction of the floors of buildings, appears to have been first introduced by Dr. Henry Hawes Fox, who applied it to a lunatic asylum in Gloucestershire, in 1833-4; and in the year 1844 he took out a patent for its application to other buildings of a similar character. It is not stated whether Dr. Fox employed cast or wrought-iron beams in the Gloucestershire asylum, but we apprehend they were cast-iron. But be that as it may, wrought-iron bars, for the joists of floors covered with flags, have been used in drying-houses in Lancashire for the last forty years; and beams with flanges, as in the French system, have been employed for the deck beams of ships for the last twenty to twenty-five years. It is, however, from the time when the lengthened series of experiments were undertaken to determine the form and strength of the tubular bridges which cross the river Conway and the Menai Straits, that we may safely date the introduction of wrought-iron for floors and public buildings upon a large and extended principle of construction.

Figs. 41 to 43 exhibit the French systems of construction, and Figs. 44 to 47 are sections of the fire-proof floors introduced into England by Messrs. Fox and Barrett.

Iron Roofs.—These constructions date from a recent period in the application of iron; some few, indeed, were made before the close of the last century, but their employment was very limited previously to the introduction of cast-iron in the construction of Messrs. Phillips and Lee's fire-proof factory at Manchester. During the rapid extension of the cotton manufacture, most of the fire-proof mills were covered with iron roofs of the form represented in Fig. 48. This description of roof, with its series of arches, was very convenient, as it gave a spacious room in the attic-story, either for machinery or for other purposes. Perhaps the only drawback to its employment was its expense, which amounted to about the same sum as the cost of an additional story.

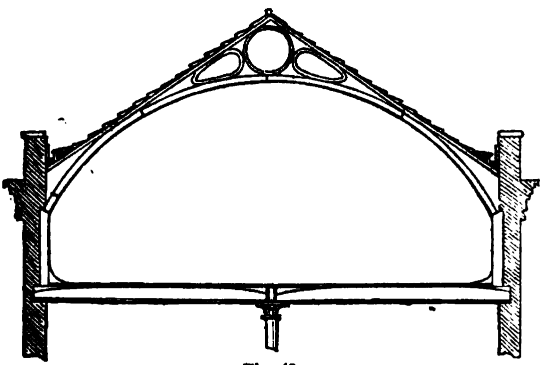


Fig. 48.

Another form of roof was introduced by Messrs. Fairbairn and Lillie, of

Manchester, in 1827, and has been very generally adopted since that time for large buildings, railway-stations, and other structures where the span does not exceed fifty feet. It is a simple and effective roof, composed of trussed cast-iron principals, and iron rods on which the slates are laid with iron nails or pegs. Of recent years, and since the introduction of railways, the cast-iron has given place to wrought-iron of the T form; and considering the facilities with which this material can be obtained from the rolls, it is probably one of the simplest and most effective roofs that can be made. In Fig. 49, *a a* is the T iron principal; *c c*, wrought-iron tie-rods fixed upon the principal by shoes at either end, and supporting the roof by means of the cast-iron strut

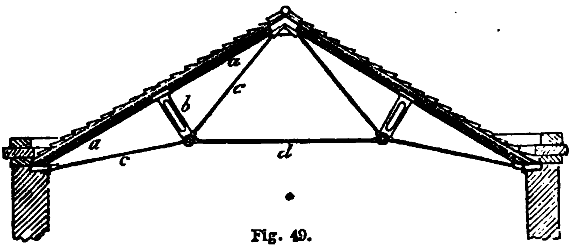


Fig. 49.

b; the tie-rod *d* holds the roof in place by resisting its tendency to force the walls outwards.

Roofs of wider span are of greater complexity, and require to be carefully constructed, in order to give the necessary rigidity and retentiveness of form. Every pair of principals composing such structures should be self-supporting—that is, should have sufficient stiffness within itself to sustain a load of 40 lbs. to every square foot of roof, without yielding to pressure or causing any thrust upon the side-walls of the building. We have always found this test to allow a safe margin; and in our opinion every roof, or rather a pair or two pairs of principals, in new constructions, should be tested up to that standard. Two examples will be sufficient to explain the principles of construction, and to show the system generally adopted in this kind of roof.

Fig. 50 is a section of the iron roof over the Lime-street Station, Liverpool, constructed by Mr. Richard Turner, of the Hammersmith Iron-works, Dublin. Extreme length, 374 feet; and breadth, 153 feet 6 inches.

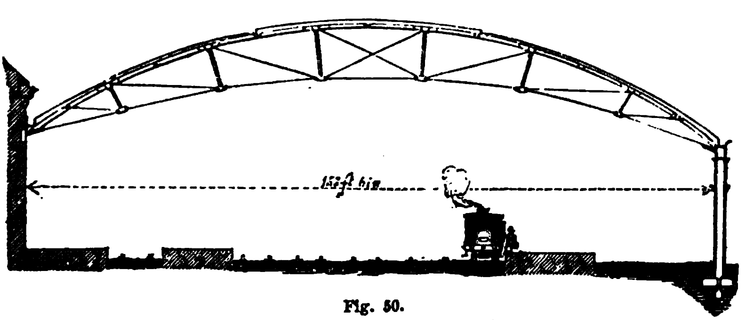


Fig. 50.

The roof consists of a series of segmental principals or girders, fixed at intervals of 21 feet 6 inches from centre to centre. These principals are trussed vertically by radiating struts, made to act by straining the tie-rods and diagonal braces; they are trussed laterally by purlins, placed over the radiating struts and intermediately between them; also by diagonal bracing, extending from the bottom of the radiating struts to the top of the corresponding ones in the adjoining principals.

Each principal is composed of a wrought-iron deck-beam, nine inches in depth, with a plate ten inches wide and a quarter of an inch thick, riveted upon the top. This curved rib is formed of seven pieces, connected with each other at the points where the radiating struts are attached by means of plates riveted on both sides. There are six radiating struts in each rib, varying in length from six to twelve feet; they are seven inches in depth, and are attached to the tie-rods by wrought-iron link plates. The sectional area of the tie-rods is 6½ inches.

The diagonal braces hold the struts tight up against the principals, and assist the tie-rods in giving the required rigidity to the principals; they are formed of round iron 1⅝ inch in diameter. The ends of the principals are fixed in chairs of cast-iron; those on one side resting upon a solid plate, and the others upon rollers, which have the power of traversing a space of three inches, also upon a metal plate, so as to admit of any expansion or contraction of the rib, though up to the present time no motion has been observed. The roof is covered with galvanized corrugated wrought-iron plates, and with rough plate-glass.

The total cost of this roof was about £15,000, and the time occupied in its erection was about ten months.

The superiority of a roof of this kind over the ordinary slated roofs in small spans is at once evident; not only is the space occupied by the intermediate columns or supports saved, and every obstruction to the use of sidings removed, but the iron roof is much more durable, and is not subject to decay to the same extent as those composed of wood.

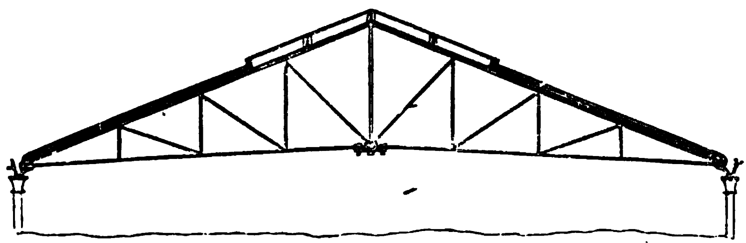


Fig. 51.

Fig. 51 is a section of one of the larger spans of the new Smithfield Market, Manchester. The space to be covered by this roof is 440 feet long by 244 feet wide. It is composed principally of wrought-iron, and consists of two central spans of fifty feet each. The whole is supported by cast-iron

gutter girders, of an average length of twenty-three feet each, resting on columns about twenty-five feet high. At the apex of each roof is a skylight fifteen feet wide on each side of the ridge, running the whole length of the market, and supported on Louvre framing, by which ample ventilation is secured. The total area of glass is upwards of 60,000 square feet.

We might introduce the splendid new roofs over the stations at Birmingham and Paddington—the first by Messrs. Fox, Henderson, & Co., the latter from designs by Mr. Brunel; but as these are familiar to travellers, architects, and builders, it will not be necessary to describe them here. We may, however, notice, that in France some beautiful roofs have been constructed of wrought-iron; that over the Paris and Versailles railway-station is composed entirely of riveted plates and angle iron: others are also in use similar to those constructed in this country. All these structures are to be seen; and we recommend them to the patient examination of the mechanical student as substantial lessons in practical science.

Iron Buildings.—Before leaving the subject of the application of iron, we would refer to the manufacture of houses, churches, &c., entirely of iron, which has assumed an important place in iron application of late years. The difficulty of obtaining building materials, and the high price of labour in Australia and other colonial settlements, has created a demand for constructions of this kind, which, being prepared in England, may be taken out and put up in a short time, and without much labour. The bulk and weight of wooden constructions have rendered them to some extent unavailable in this respect; and hence recourse has been had to *iron*, which has answered the purpose admirably, both as regards durability and security from fire.

One of the earliest attempts to employ iron in this way was made by Mr. Fairbairn in 1839, when he constructed an iron corn-mill for the Seraskier, Halil Pasha, Commander-in-Chief to the Sublime Porte. The walls were of plates of sheet-iron of suitable thickness, consolidated and bound together by cast-iron columns and by strong cast-iron girders. It is surmounted by an arched roof, formed of plates of corrugated sheet-iron; and forms probably one of the finest and most perfect iron constructions executed in this country. The interior was intended to be lined with wire-gauze, and plastered so as to leave a stratum of air between the interior plaster and the external plates. This building was erected at Constantinople, and is now occupied as a flour-mill.

Fig. 52 is a sectional elevation of an iron custom-house, constructed by Messrs. E. T. Bellhouse & Co., of Manchester, and will serve to show to what extent iron may be applied in constructions of this kind. This custom-house was intended for the town of Payta, in Peru; and, together with a large iron warehouse, was erected in Messrs. Bellhouse's yard, and then taken to pieces in sections and transmitted to its destination.

It consists of a square block seventy feet each way, of two lofty stories, surrounded by a balcony at the second floor level and an ornamental veranda, each projecting two yards from the face of the building. The roof inclines upwards from each side, meeting at a square platform C twenty-three feet

across, and above which rises a circular tower, B, seventeen feet high and fifteen feet in diameter, which is surmounted by an upper circular tower, A, and flag-staff. The external shell consists of strong cast-iron pilasters and cross

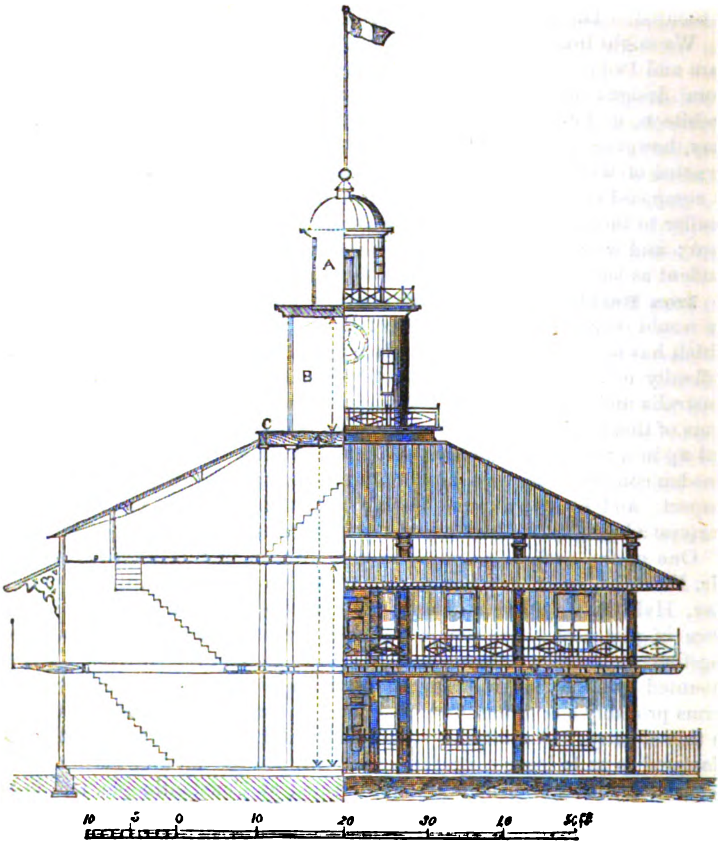


Fig. 52.

pieces of wrought angle-iron, to which are bolted the galvanized corrugated sheets No. 16 wire-gauge. The whole of the sides and ceilings of the various rooms and passages are lined with boarding, upon which Croggon's patent inodorous felt is nailed, which will be papered with common lining paper, and finished with coloured paper-hangings. Windows opening in the manner of French casements afford light to the rooms.

Fig. 53 represents a cross section, and Fig. 54 a side view of the cross-

bar of angle-iron A and timber-batten B, to which are attached the galvanized corrugated sheets C on the outside, and the lining-boards D on the inside.

In closing these remarks, it is evident that there is yet much to be done on the part of the architect and engineer in the appliance of iron to the construction of buildings; and it is much to be regretted that, notwithstanding the extent of the iron manufacture of this country, and the comparative cheapness of production, we should be behind our continental neighbours in its application to buildings and dwelling-houses.

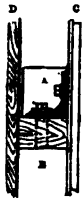


Fig. 53.

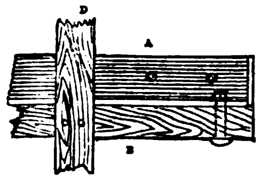


Fig. 54.

With all our boasted skill and our immense production, we have never been able to roll iron beams nor apply them to the same extent as the French; and our architects have almost totally neglected the application of this important and highly useful material. Whether this omission arises from prejudice or ignorance, or from both, we are unable to determine; but such has been the apathy or want of foresight of this class of men, that they have allowed others of more humble pretensions to go before them. There is now open for some young and active aspirant a new and a wide field of action in construction as well as design; and it only requires a man of taste and original thought to strike out for himself a perfectly new style of architecture, founded on a more accurate knowledge of the properties of iron and its appliance to the wants of his profession.

CHAPTER XXII.

ON THE APPLICATION OF CAST AND WROUGHT-IRON TO RAILWAYS, BRIDGES, &c.

THE consumption of iron for railway purposes and for bridges has been so enormous since 1830, as to be sufficient in itself to mark the commencement of a new era in the history of its application. At no former period in the history of nations did changes of such magnitude ever take place; and considering the thousands of miles of railway which have since been constructed, at home and abroad, including the immense amount of rolling stock,—and moreover when we consider that iron-shipbuilding commenced about the same period,—it will be evident that the impetus given to the iron

manufacture of this country has been unparalleled in its extent in the history of any other manufacture, that of cotton probably alone excepted.

In railway constructions, iron is employed almost to the exclusion of every other material. The rails, chairs, and machinery, are almost entirely of iron; and even the carriages, waggons, and other appliances, are, in many cases, of the same material. The wheels, tyres, springs, and draw-bars, are all of this material; and even the coverings of many of the carriages and waggons are composed of iron frames and plates.

The forms of the rails, chairs, and the wheels which run upon them, are so well-known as scarcely to require a description. The rails, however, vary; and we shall therefore give a brief sketch of their application. In the earlierst ages of railroad construction, the lines laid down from the collieries at Newcastle on-Tyne to the river were (in the reign of Charles II.) composed of longitudinal pieces of wood laid on transverse sleepers. These continued for many years without change, excepting only occasional repairs of thin iron bars nailed on the surface of the wooden rails. About the year 1807, the introduction of iron was first attempted, the rails then used being made of cast-iron three feet long, and of the fish-bellied form, shown in Fig. 55. These subsequently gave place to the malleable-iron rail—still fish-bellied—until at last it was found more desirable to have the parallel rail with top and bottom flange, as shown in the accompanying diagrams, Figs. 56, 57, and 58, in which it is seen as it appears when fixed in its chair, fastened down by pins or trenails to a transverse sleeper embedded in the ballast of the roadway. As a substitute for this rail, other

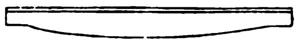


Fig. 55.

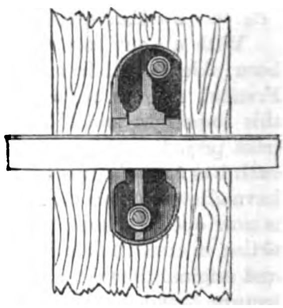


Fig. 56.—Plan.

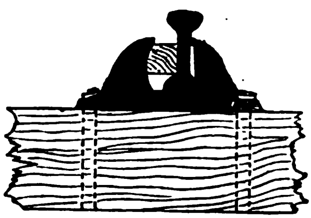


Fig. 57.—Section.

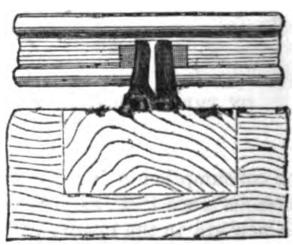


Fig. 58.

forms have subsequently been used; such, for instance, as the box-rail, Fig. 59, which lies direct upon a longitudinal sleeper throughout its whole length, and the large trough, or saddle-back rail, which is somewhat similar to Fig.

59, but with flanges spread out, so as to rest upon the gravel, without sleepers, requiring only tie-rods and wooden frames about every six feet to keep it in gauge. The wheels of locomotive engines, carriages, and waggons, are all of iron, with malleable-iron tyres, which latter never vary their sectional form, whatever may be the diameter of the wheel or the nature of the load they have to bear.

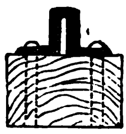


Fig. 59.

The next structures to which iron is applied upon a large scale are bridges; and the employment of these is not confined to railways, but is extended to all cases where wide valleys and rivers have to be crossed.

Iron Bridges.—Iron bridges are of recent origin; and although the powers of resistance, rigidity, and other properties of this material, have been known from an early period, its uses for many centuries were limited to instruments of war and purposes of agriculture, by the difficulty with which it was worked, and the cost at which it was produced. But as civilization advanced, and the useful and industrial arts increased, the manufacture of iron from the ores became a matter of deep importance; and hence followed improvements in the manufacturing processes, which cheapened the production, while the demand for it was greatly increased by its application to purposes for which it had been supposed it could never be employed. Amongst these were bridges; and the first successful application of iron to these constructions was the cast-iron arch across the Severn at Colebrookdale, erected in 1779. It is stated that attempts were made in Italy and in France at an earlier period to construct cast-iron bridges, but they were never erected; and their introduction properly belongs, therefore, to Mr. Pritchard, the designer, and to Messrs. Darby and Reynolds, the con-

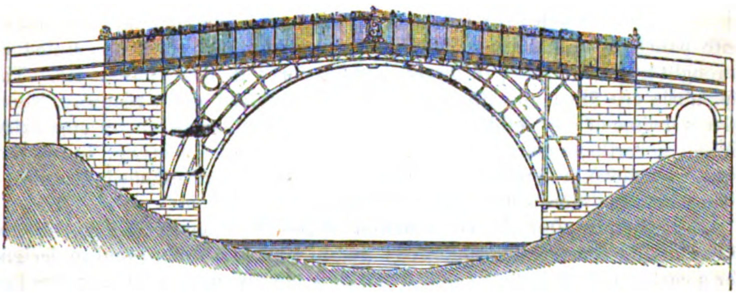


Fig. 60.

structors, of the Colebrookdale Bridge. Fig. 60 is an elevation of this bridge, which consists of five ribs of 100 feet span each, consisting of three concentric rings of cast-iron, one only being entire. This is doubtless a defective construction; but considering the imperfect state of our knowledge at the time, it is probably as perfect as could reasonably have been expected, as a first essay in iron construction on so large a scale.

The next cast-iron bridge was one of 130 feet span, erected by Telford

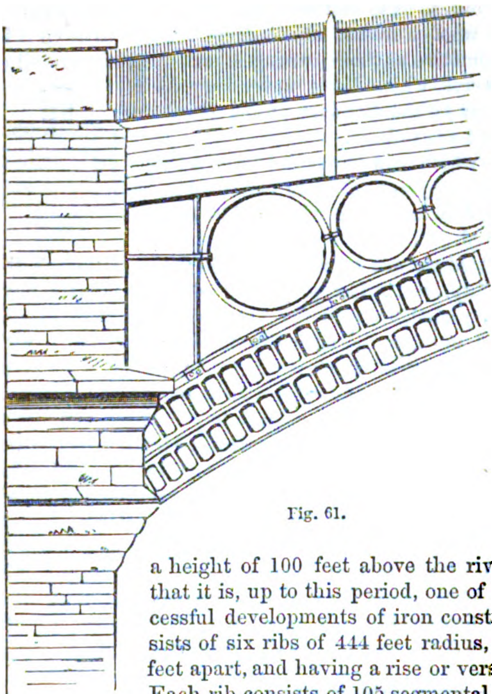


Fig. 61.

over the Severn, near Shrewsbury, in 1795; and soon after the Wearmouth Bridge, from the designs of Mr. Thomas Wilson, was constructed over the Wear in 1796. This extraordinary bridge is remarkable alike for the length of the span (236 feet), the boldness with which it was conceived, and the rapidity with which it was constructed. Messrs. Walker, of Rotherham, were the contractors; and whether we consider the vastness of the experiment, or the airy lightness of the structure, at a height of 100 feet above the river, we must at once admit that it is, up to this period, one of the largest and most successful developments of iron construction. The bridge consists of six ribs of 444 feet radius, placed at distances of six feet apart, and having a rise or versed sine of thirty-four feet. Each rib consists of 105 segmental castings; they are formed into panels by radial bars, which form voussoirs, 105 of which, united by wrought-iron arcs, fitted in grooves and secured in bolts, form a rib. The spandrils are filled up with cast-iron circles, supporting the roadway, which give a degree of airy lightness to the construction that borders on insecurity. It has, nevertheless, stood the test of more than half a century; but at present, we believe, it is under consideration to have it strengthened or replaced by a wider and more substantial structure.

Immediately after the construction of the Wearmouth Bridge, several other similar constructions followed; and in 1801 Mr. Telford sent in designs for a cast-iron bridge of *six hundred feet span*, and with a rise of sixty-five feet above high-water, intended to replace one of the London bridges. This splendid arch across the Thames was commenced, but was afterwards abandoned. In 1819, the late Mr. John Rennie erected the Southwark cast-iron bridge, which, for architectural effect and colossal proportions, stands unrivalled in the history of cast-iron bridges. For simplicity in construction, extent of span, and the durable character of the structure, as a whole it has no competitor, even at the present day, among the numerous bridges of this description which have been erected since that time.

One of the most beautiful of this description of bridges constructed in this country is that of Tewkesbury, designed by Telford. It is of 170 feet span, and consists of six ribs, and spandrils of light diagonal work. It has a rise of seventeen feet.

Fig. 61* represents two out of the three arches of a beautiful bridge erected over the Trent. Each arch is of 100 feet span and 10 feet rise; every rib, together with the roadway bearer and its supports, was made complete

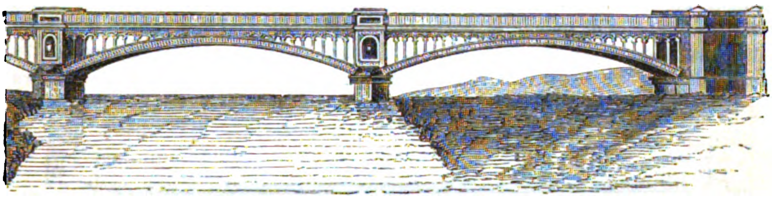


Fig. 61*.

in three single castings by the Butterley Company. The total weight of cast-iron in this bridge is 280 tons, and of wrought-iron 5 tons; the roadway is of timber, and carries a railway.

Cast-Iron Girder Bridges.—Other bridges besides those of the cast-iron arch have been introduced, chiefly for small spans; and these are called beam or cast-iron girder bridges. They have been in great demand for railways where the span does not exceed forty or fifty feet, and they are also used for common roads crossing canals, &c.; but in spans above fifty feet they cannot be depended upon, unless formed in parts and jointed together with bolts. The best form in the larger spans is the flat arch, with a versed sine of about $\frac{1}{20}$th the depth of the chord. This description of beam partakes of the properties of the beam as well as the arch: unlike some, it does not entirely depend upon voussoirs as an arch of equilibrium, being partly retained in form by the unyielding nature of the abutments resisting the thrust of the weight; and from its connection at the joints by bolts, it becomes a beam with a large camber, supporting the load by its resistance to compression and extension.

Bowstring bridges, having the roadway suspended from strong cast-iron arches, have also been introduced; but as these bridges are expensive, and as all combinations of a rigid with a ductile material are objectionable,* it will not be necessary to enlarge on their construction; and the same may be said of bridges with trussed cast-iron girders.

Chain and Wire Bridges.—Bridges upon the principle of suspension are of ancient origin, and appear to have been used from an early date in China, and among the Peruvians; they were composed of ropes, on which the roadway, consisting of logs of trees laid transversely, was placed; but they were of primitive construction, and being composed of perishable materials, were never used where a more durable structure could be erected. Their introduction into Europe is due to the use of iron; and the first suspen-

* See experiments on the trussed cast-iron girders, page 417, et seq.

sion bridge thus constructed was thrown across the river Tweed near Melrose. Another suspension bridge, composed of chains and designed by Captain Brown, spans the Tweed a little above Berwick. After this the Newhaven and Brighton chain-piers were erected, and ultimately the colossal structures of the Conway and Menai Straits. Some beautiful bridges of this description have also been built by the late Mr. Tierney Clark; one at Hammersmith, and another crossing the Danube at Pesth. Wire bridges have also been constructed in this country, but only to a limited extent; they are, however, much in demand in many parts of France and Germany, and we may instance those over the Rhone, and the light and elegant structure of 870 feet span at the town of Freiburg, in Switzerland. Most of these bridges are composed of wire bound into ropes and cables of strength proportional to

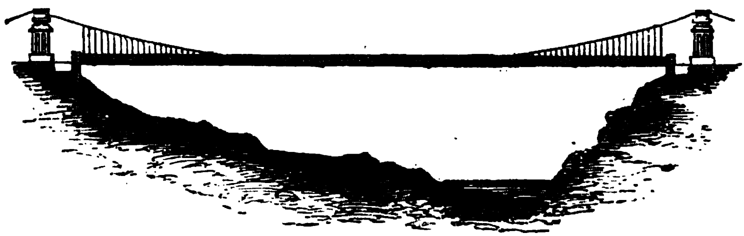


Fig 62.

the extent of the span and the load they are intended to bear. As all these bridges are on the principle of the catenary, whether formed of wire or of chains, it will be sufficient to take one or two of the best as examples of the whole.

Fig. 62 represents the Freiburg suspension bridge over the valley of the Sarine, of the enormous span of 870 feet, and 167 feet above the level of the river; and for boldness of conception and beauty of execution, it is a model of its class.

The bridge is composed of four main cables, two on each side of the roadway; each of these is composed of twenty strands, which were made and raised to their place separately, on account of the difficulty of raising so great a weight entire. These strands are composed of wire about one-tenth of an inch thick, laid parallel and subjected to a testing strain of 220 lbs. each, and then bound together by wire at every three or four feet, and coated with a mixture of oil, litharge, and soot, to prevent their rusting. Each cable consists of twelve strands of fifty-six wires each, and eight of forty-eight wires each, bound up into a cylindrical form by wire at every second foot; and when complete was five and a half inches in diameter, and 1228 feet long.

The piers on either side are founded on the solid rock, and rise sixty-six feet above the level of the road. They present to the passenger an arched opening forty-three feet high, each of the sides bearing three pilasters and an entablature gracefully arranged as a Doric portico. In the upper part of the

piers is placed the apparatus for receiving the cables; it consists of three rollers, giving as many points of support to the cables, which are allowed to spread out and form a band at these points. Every facility is afforded by these friction rollers for slight movements of the cables, in consequence of changing temperature or similarly acting agents; while by their disposition the cables are not damaged by sudden bends.

Beyond the piers, sloping galleries are cut, at the bottom of which are four shafts, sunk to a depth of fifty-two feet. In these masonry is fitted to support the cables, which are carried down to the bottom and there secured.

When the cables had been raised to their position, and the strands on each side bound into two cables by iron wire, the suspension cords, as shown in Fig. 63, were fixed by saddles, *e*, embracing the cables. At the bottom a stirrup and hook-loop supports the cross-beams, over which are the longitudinal planking, &c. The suspension cords consist of thirty wires, and are one inch in diameter. The width of the roadway is twenty-one feet; the deflection of the main cables sixty three and a quarter feet; weight of the bridge, 296 tons; cost, £24,000.

Fig. 63.

Another bridge of colossal dimensions has been erected over the Niagara river below the Falls. It carries the railroad which connects Canada with the state of New York, and is composed, like the Freiburg bridge, of four wire cables, each ten inches in diameter and composed of 3640 wires. From the suspending quality of the wire, it is calculated to bear upwards of 120,000 lbs. per square inch. It is of 821 feet span and 245 feet above the river, and has been in operation for nearly three years.

It was our intention to have given a drawing of one of the most important and colossal chain bridges that has yet been executed, namely, the Menai Suspension Bridge, designed and executed by the late Mr. Telford; but we have already exceeded our limits, and must content ourselves with a brief notice of this important structure, rather than a description calculated to do justice to a work that cannot be looked upon in any other light than as a great national undertaking. Suffice it, therefore, to observe that the Menai Suspension Bridge was the first structure of the kind to unite the Island of Anglesey with the mainland, at a narrow point of the Straits a little above the old Bangor ferry. It is 580 feet span, and 100 feet above the tide-way; and the towers, composed of Anglesey marble, approach close to the edges of the rock on each side, so as not to impede or in any way injure the navigation of the Straits.

For symmetrical appearance, and due proportion of the parts, this speci-

men of the catenary principle is one of the best and most effective structures that has yet been completed in this or any other country.

In the manufacture of the chains, a great improvement has been effected since the completion of Mr. Telford's bridge across the Menai Straits. The bars or plates which form the links were in past time forged into shape at the ends for boring, to receive the link-pin, and were then welded together to the proper distance; but as these welds were sometimes imperfect, and as the security of the bridge depended upon the soundness of every link, it was reserved for Mr. Tierney Clark, and Messrs. Howard and Ravenhill, Bermondsey, London, to obviate this defect by an ingenious adaptation of machinery for rolling the links to the required shape and length, at one and the same process. This method of construction removed all objections, and insured perfect safety, in so far as regards the soundness of the material. Fig. 64 is a representation of one of these links, generally about six feet long, five or six inches wide, and one inch thick; six or eight of these are united by a strong pin, duly proportioned to the strength of the plates.

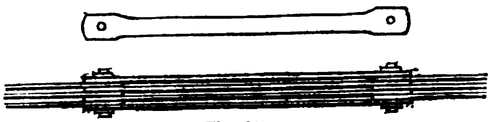


Fig. 64.

These links were first used in the bridge over the Danube at Pesth, and subsequently for raising the Conway and Britannia tubes.

Another structure of a similar kind to those denominated chain bridges, is known as Dredge's suspension bridge; and the principle on which it is constructed is said to effect an important economy of material. Mr. Dredge, instead of making his chains of the same strength throughout, makes them of sufficient strength at the points of suspension to support with safety the greatest possible load which can be brought upon the bridge, and tapers or diminishes them from thence towards the middle of the bridge, where the strain becomes essentially evanescent.

There is another peculiarity about Mr. Dredge's bridge—viz. that the suspending bars which support the roadway are hung obliquely, not vertically, at angles which vary in magnitude from the abutments to the middle of the bridge. Each bar is considered to perform its part in supporting the load, in proportion to its distance from the abutment, drawn into the sine of the angle of its direction; so that the entire series of suspending bars transmits the same tension to the points of support as would be transmitted by a single bar reaching from thence to the middle of the bridge.

Fig. 65 is an elevation of a bridge on this principle, erected at Balloch Ferry, Dumbartonshire, which will explain this method of construction. The entire length of the bridge is 292 feet; the length of the middle span 200 feet; roadway 20 feet wide. The piers are octagonal towers, 15 feet by 9 feet at the base, and 40 feet above the bed of the river. The main chains are formed of $\frac{7}{8}$ round bars, laid side by side; thirteen in number over the towers, and diminishing by one bar at every link, till at the centre of the bridge the chain is reduced to a single bar. The links upon the towers are 6 feet long, the

others 9 feet. The weight of the chains is 13,874 lbs. The oblique rods are of ¾ inch round iron; the chains being connected with the platform by two of these at each link.

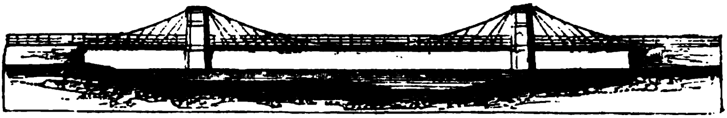


Fig. 65.

Several of these bridges have been constructed in India, but we have yet to learn in what respect they differ from ordinary suspension bridges, either in regard to cost or security. It has been asserted that they are much cheaper; but they must not be considered as less expensive, if a reduction of price is attained by the sacrifice of part of the strength of the bridge.

Tubular, Tubular Girder, and Plate Bridges.—It will not be necessary to trace the origin and course of the experiments which were instituted to determine the proper form of the tubular bridges which cross the Conway River and the Menai Straits; they are already well-known. Suffice it, therefore, to observe, that in order to comply with the demands of the Admiralty in carrying the Chester and Holyhead Railroad across the Menai Straits, in such a manner as not to impede the navigation, it was found necessary to construct a bridge of colossal dimensions, having four spans, and leaving a clear opening on each side of the centre pier of 460 feet, with an elevation of 100 feet between the bridge and the high-water level.

This could not have been accomplished by the ordinary applications of iron, such as cast-iron arches or chain bridges; the former not giving sufficient height above the water-level, and the latter, from their flexibility, having been shown to be inadequate for the support of railway trains* and railway traffic. It was ultimately resolved to erect wrought-iron tubes, through which the trains might pass. This project of crossing the Straits was considered by some mathematicians and engineers at the time as perfectly Utopian; and it was left to Mr. Stephenson and Mr. Fairbairn to solve the problem by carrying it into effect. A laborious series of experiments was instituted, which pointed out the principle on which such a structure should be designed, determined the formula for calculating its strength, and established an entirely new system of construction. These experiments have already led to the use of wrought-iron to an immense extent, and have afforded to the public greatly increased facilities for railway and other communication.

It may be observed, that the original conception was to have a cylindrical or elliptical tube supported by chains—the former giving sufficient rigidity to prevent the dangerous vibratory action of ordinary suspension bridges, the latter affording the necessary support; but the experiments led to a

* The only successful application of the suspension bridge to railway purposes is the Niagara Bridge; but this, although stiffened in every possible manner, can only be safely crossed at the rate of about three or four miles an hour.

different and much more satisfactory construction, by showing that the tubes might be made self-supporting, and much stronger, more rigid, and less expensive than could have been secured by the employment of any other auxiliary support. The following general deductions from the experiments will be instructive:—

Comparative Weights and Strengths of Cylindrical Tubes.

No. of Exp.	Dist. betwn. supports.	Weight of tube.	Breaking weight.	Ratio.	Diameter.	Thickness.
	ft. in.	lbs.	lbs.		in.	in.
1	17 0	102	3040	1 : 29·0	12·18	·034
2	17 0	107	2704	1 : 25.2	12·00	·037
3	15 7½	392	11,440	1 : 29·1	12·40	·131
4	23 5	334	6400	1 : 19·1	18·26	·058
5	23 5	346	6400	1 : 18·5	17·68	·063
6	23 5	777	14,240	1 : 18·3	18·18	·119
7	31 3¼	907	9760	1 : 10·7	24·10	·095
8	31 3¼	1385	14,240	1 : 10·2	24·30	·096
9	31 3¼	1005	10,880	1 : 10·8	24·20	·135

Comparative Weights and Strengths of Elliptical Tubes.

No. of Exp.	Distance between supports.	Weight of tube.	Breaking weight.	Ratio of weight to strength.	Dimensions of tube. Diameters. Trans.	Conjug.
	ft. in.	lbs.	lbs.		in.	in.
19	17 0	109	2,100	1 : 19·2	14·62	9·25
20	24 0	708	17,076	1 : 24·1	21·66	13·50
21	24 0	357	7,714	1 : 21·7	21·25	14·12
22	18 6	232	6,867	1 : 29·6	12·00	7·50
22	18 6	232	5,648	1 : 24·3	12·00	7·50
24	17 6	374	15,490	1 : 40·0	15·00	9·75

Comparative Weights and Strengths of Rectangular Tubes.

No. of Exp.	Distance between supports.	Weight of tube.	Breaking weight.	Ratio of weight to strength.	Dimensions of tube. Depth.	Width.
	ft. in.	lbs.	lbs.		in.	in.
14	17 6	202	3,738	1 : 18	9·6	9·6
14*a*	17 6	384	8,273	1 : 21	9·6	
15	17 6	255	3,788	1 : 14	9·6	
15*a*	17 6	255	7,148	1 : 28	9·6	12·0
16	17 6	317	6,812	1 : 21	18·25	9·25
16*a*	17 6	317	12,188	1 · 38	18·25	9·2
17	24 0	788	17,600	1 : 22	15·0	2·25
23	18 6	267	8,812	1 : 33	13·0	8·0
29	19 0	500	22,469	1 : 50	15·4	7·75

Now, it may be shown that the ratio of the weight of a tube to its breaking-weight, varies directly as the depth of the tube when its length is constant; in order, therefore, to ascertain the comparative strengths of these tubes, we shall reduce some of the best of each sort to the same depth.

Thus, Nos. 4, 20, and 17, have nearly the same length; hence, by reducing them to the same depth, we find their relative strengths to be as follow:—

No. 4, 10·5; No. 20, 11·1; No. 17, 14·6.

Taking Nos. 1, 24, and 15*a*, we find

No. 1, 24·4; No. 24, 26·6; No. 15*a*, 29·1.

Again, for Nos. 22 and 29, we find

No. 22, 24·6; No. 29, 32·4.

Hence it appears that the rectangular tubes are the best, and that the elliptical ones are next in order.

It is desirable that we should have some formula, which will enable us to estimate the comparative strength of these tubes, whatever may be their form or relative dimensions. For this purpose it may be shown that the following formula is approximately true for all tubular girders,—viz.

$$W = \frac{AdC}{l} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1.)$$

where $W =$ the breaking-load, A the area of the whole cross section of the tube in square inches, $d =$ the depth of the tube, $l =$ the distance between the supports, and $C =$ a constant, which must be determined by experiment for the particular *form* of the tube. Moreover, the value of C determined for different forms of tubes, will enable us to ascertain their comparative strength. From the above relation we have

$$C = \frac{Wl}{Ad} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2.)$$

Thus, to find the value of this constant for Experiment 29, we have

$$W = \frac{22470 + \frac{1}{4}(500)}{2240} = 10{\cdot}142 \text{ tons}$$

$$l = 19 \times 12,\ d = 15{\cdot}4, \text{ and } A = 7{\cdot}048 \text{ square inches;}$$

$$\therefore C = \frac{10{\cdot}142 \times 19 \times 12}{7{\cdot}048 \times 15{\cdot}4} = 21{\cdot}3 \text{ tons.}$$

Proceeding after this manner, the following tables have been calculated.

Comparative Strengths of Tubes, indicated by the Value of C.

Cylindrical Tubes.

No. of Exp.	Breaking-weight in tons, or W.	Area section, or value of A.	Value of the constant C in tons
1	1·38	1·5612	14·8
2	1·23	1·3948	15·0
3	5·19	5·1032	15·4
4	2·93	3·3385	13·5
5	2·93	3 5048	13·3
6	6·48	6·7970	14·7
7	4·13	7·1928	9·9
8	6·66	. .	9·9
9	5·08	7·4506	10·5

Elliptical Tubes.

No. of Exp.	Breaking-weight in tons, or W.	Area section, or value of A.	Value of the constant C in tons
20	7·78	7·1824	14·4
21	3·81	3·3300	11·9
22	3·12	3·3720	17·1
24	5·49	7·0010	17·8

Rectangular Tubes.

No. of Exp.	Breaking-weight in tons, or W.	Area section, or value of A.	Value of the constant C in tons
14	1·71	3·20	11·7
14*a*	3·73	5·32	15·3
15	1·74	4·04	9·5
15*a*	3·24	4·04	17·8
17	8·03	8·00	19·3
25	5·05	2·90	28·6
29	10·13	7 05	21·3
30	5·83	5·75	16·1
31	8·05	6·73	15·1
33	37·95	41·82	15·1
35	58·73	45·82	21·1
36	68·56	50·82	22·5
41	89·15	55·47	26·7

In the rectangular tubes, Nos. 14*a*, 15*a*, 17, 25, 29, 35, 36, and 41, appear to have had, nearly, a proper distribution of the material; the mean value of C estimated from these is 21·5 tons, which is considerably greater than the value of C deduced for any of the cylindrical or elliptical tubes.

	Mean value of C.
For the cylindrical tubes	13·03 tons.
For the elliptical tubes.	15·3 tons.
For the rectangular tubes.	21·5 tons.

Hence we infer that the rectangular form of tubes is considerably stronger than either the cylindrical or elliptical form.

From the formula eq. (1.) we may deduce another formula, containing, in one expression, the essential data of the problem. It will not be necessary to give here the steps of the investigation: the result will be sufficient.

$$L_1 = \left(\frac{l_1}{l}\right)^2 \left\{L - \frac{l_1 - l}{l} \cdot w\right\} \text{ tons} \quad . \quad . \quad . \quad . \quad (3.)$$

which expresses the breaking-load L_1, of a tube l_1 feet long, and in all respects *similar* to an experimental tube, whose length is l feet, weight $2w$ tons, and breaking-load L tons. This formula is convenient for calculation.

Strength of the Conway Tube.—Experiments 41 and 42.—In the model tube, Experiment 41, $l = 75$, $L = 86{\cdot}25$ tons, $w = \frac{5{\cdot}8}{2} = 2{\cdot}9$ tons. In Experiment 42, $l_1 = 400$; hence we have by eq. (3.),

$$L_1 = \left(\frac{400}{75}\right)^2 \left\{86\cdot25 - \frac{400-75}{75} \times 2\cdot9\right\}$$

$=$ 2096 tons, which is the breaking-load of the tube; and hence the breaking-weight, $W_1 = 2096 + \frac{1300}{2} = 2746$ tons, 1300 lbs. being the computed weight of the Conway tube.

Again, adopting formula (I.), we have,

$$A = 1530,\ d = 25\cdot5,\ l = 400,\ \text{and}\ C = 26\cdot8;$$

$$\therefore W = \frac{AdC}{l} = \frac{1530 \times 25\cdot5 \times 26\cdot8}{400} = 2614 \text{ tons},$$

which nearly coincides with the former result.

Deflections of the Conway Tube.—In order to discover the law of the deflections in tubular beams, we shall first consider the results of Experiment 41. Adding $\frac{5}{8}$ths of the weight of the tube to the numbers in the column of weights in the table of results, we have—

No. of Exp.	Deflecting weight in tons.	Deflections in inches.
4	70,411	1·48
8	122,797	2·70
12	156,580	3·58
16	172,878	3·98
20	185,225	4·47
24	197,307	4·81

Here we find the approximate relation of the deflections and deflecting weights to be expressed by the equality

$$\delta = \frac{W}{43000}$$

That is, the deflection in inches is, approximately, the 43,000th part of the deflecting weight expressed in lbs. This relation is more accurately expressed by the equality

$$\delta = \frac{W}{38000} - \cdot4$$

Making a similar reduction of the table of results, Experiment 42, on the Conway tube itself, we have, regarding the weights as laid over the centre of the tube—

No. of Exp.	Deflecting weight in lbs.	Deflections in inches.
1	812	7·91
2	907	9·02
3	966	9·50
4	1018	10·50
5	1113	10·95

Here the deflections are pretty nearly the 101st part of the deflecting weights expressed in tons. Taking the breaking-weight just determined to be 2600 tons, we have the ultimate deflection of the tube $= \frac{1}{101}$ of 2600 $=$

25·7 inches. Now, in order to test the accuracy of these calculations, we have for similar tubes the following relation :—

$$\frac{\delta}{\delta_1}=\frac{l}{l_1};$$

that is, in the present case $\frac{\delta}{4\cdot81}=\frac{400}{75}$; therefore $\delta=25\cdot6$ inches, where the same result is obtained by two processes perfectly independent of each other.

Tubular Bridges.—The experiments to which we have just referred,

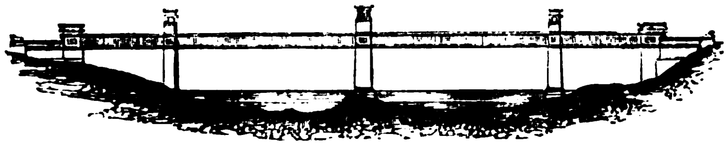


Fig. 66.

proved that a tube might be made of sufficient strength to carry the heaviest trains over rivers or arms of the sea, such as the Menai Straits, and the result was the erection of the Conway and Britannia Bridges, and the introduction of a new system of construction.

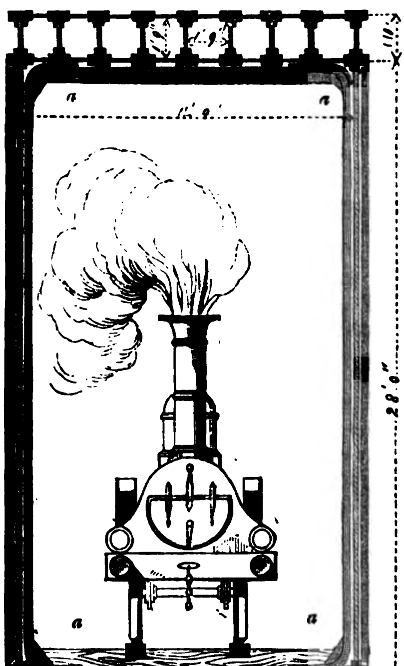


Fig. 67.

To show the manner in which the material is disposed in these bridges, we select the Britannia Bridge, of which Fig. 66 is an elevation, and Fig. 67 a transverse section through the centre of the tube.

The Britannia Bridge consists of two wrought-iron tubes, through which the train passes. The cross section, Fig. 67, will show the peculiar arrangement adopted to give the required strength to the top and bottom of the tubes to resist the forces of tension and compression acting at those parts. It will be seen that the top is constructed with eight cells, strengthened at the corners with angle irons; thus securing a large sectional area. The bottom is constructed in a similar manner with six cells; whilst, to give rigidity to the sides, and to secure

the connection of the joints between the vertical plates of which they are composed, T iron is riveted over every joint, both outside and inside, and is carried on some distance along the top and bottom, inside. The corners are also strengthened by angle plates or gussets, as shown at *a a a a*.

The following table, giving the dimensions of both bridges, will be of interest:—

	Britannia.	Conway.
Total length of each tube	1524 ft.	424 ft.
Total length of tube for both lines of railway .	3048 „	848 „
Greatest span in the clear	460 „	400 „
Height of tubes at the middle	30 „	25 „ 6 ins.
Height of tubes at intermediate piers	27 „	....
Height of tubes at ends	23 „	22 „ 6 „
Extreme width of tubes	14 „ 8 ins.	14 „ 8 „
Number of rivets in one tube	882,000	240,000
Number of rivets in the whole bridge . . .	1,764,000	480,000

The Britannia Bridge is divided into four spans, the two principal extending from the pier on the Britannia Rock to the piers on either side of the Straits, each being 460 feet in the clear; and the spans extending from these smaller piers to the embankments, being each 230 feet in the clear. The bearing on the centre pier is forty-five feet; on each side of the intermediate piers, thirty-two feet; and on the abutments, seventeen feet six inches. In both bridges the tops have the form of a parabolic curve. The total weight of the Britannia Bridge is computed to be 10,570 tons, and of the Conway Bridge 2,892 tons. The success of these gigantic structures called the attention of all engaged in engineering operations to the immense value of wrought-iron as a material of construction. The uniform strength, the facility with which it can be rolled into the various forms of plate, angle, and T iron, and the admirable manner in which it can be joined by riveting, peculiarly fit it for such structures as road and railway bridges.

Tubular Girder Bridges.—Where the span is not very large, it was found advisable not to have a large tube through which the train might pass, but to have two or three smaller tubes, or tubular girders as they are called, with cross-beams between them, over which the roadway is laid. This description of bridge was first introduced by Mr. Fairbairn; and, like the tubular bridges, was founded upon the experiments made to determine the strengths and forms of the Britannia and Conway Bridges.

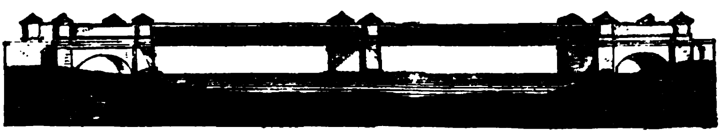


Fig. 68.

The annexed elevation of the Gainsborough Bridge (Fig. 68) will give some idea of the form of tubular girder bridges. Its total length is 332 feet, the

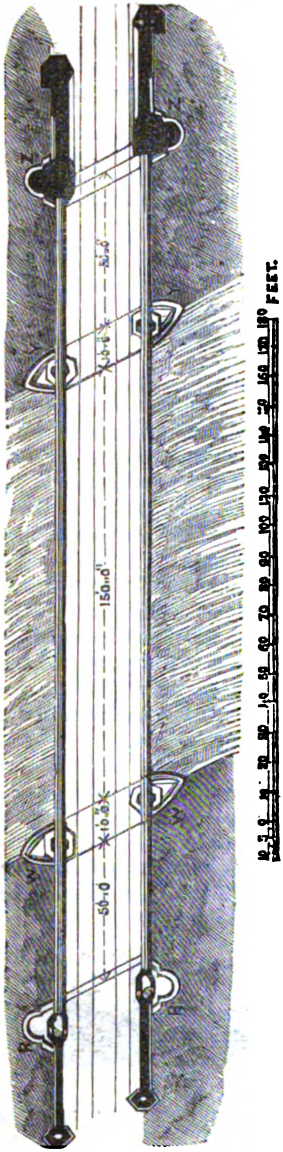


Fig. 69—Plan.

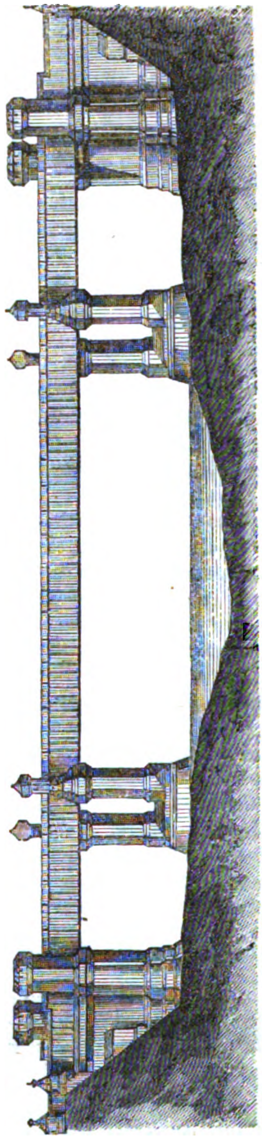


Fig. 70.—Elevation.

two main spans being 154 feet each; the width of bridge between the girders is twenty-six feet, giving ample room for a double line of railway. The thickness of the centre pier is twelve feet, and the girders have a bearing on each land abutment of six feet. The height of each girder is twelve feet at the centre pier, and sixteen feet at the abutments, and its width two feet six inches; and each consists of a hollow tube strengthened by two cells at the top, and a double thickness of $\frac{10}{16}$ inch plate at the bottom. The cross girders are composed of two beams of wood, each six inches broad by fifteen inches deep, one bolted on each side of a wrought-iron plate. The girders are placed

at an angle of skew of 50°. In all bodies submitted to a transverse strain, be they solid or hollow, those parts above the *neutral axis* are subjected to a force of compression, while those below having to support a tensile strain or force tending to tear them asunder, are exposed to compression; but the parts about the neutral axis are almost free from strain. Hence it is that in these structures the great bulk of the material is collected close to the top and bottom, while only sufficient is left in the middle to connect the two rigidly together. To accomplish this, and to attain a maximum power of resistance to compression with the minimum of material, the cellular principle was adopted in the Britannia and Conway Bridges; and it has also been applied to the equally important but less imposing structure of the bridge at Gainsborough.

It may be interesting to add one more example of a tubular girder bridge, and we select that across the River Suir, on the Waterford and Limerick Railway. This bridge has been erected some years, and may serve as a correct example of this description of bridge, though some upon a much larger scale are now in process of erection. One of these for the Victoria Railway, Australia, is to cross the Salt River, with a span of 200 feet. Two others are to carry the Aberdeen and Inverness Railway across the rivers Spey and Findhorn; the former bridge having a span of 230, and the latter three spans of 150 feet each.

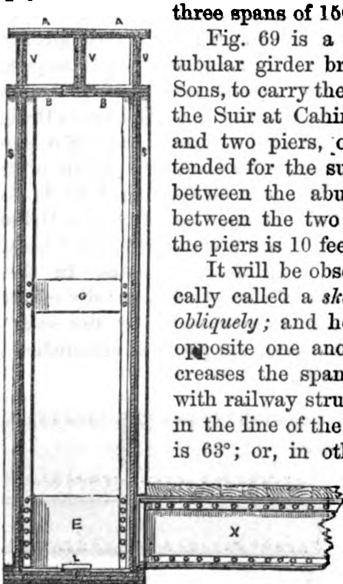


Fig. 71.

Fig. 69 is a plan, and Fig. 70 an elevation of the tubular girder bridge erected by Messrs. Fairbairn and Sons, to carry the Waterford and Limerick Railway across the Suir at Cahir. The bridge consists of two abutments and two piers, over which two tubular girders are extended for the support of the roadway. The clear span between the abutments and the piers is 50 feet, and between the two piers 150 feet. The bearing surface on the piers is 10 feet, and on the abutments 5 feet.

It will be observed that the bridge is what is technically called a *skew* bridge—that is, it crosses the river *obliquely;* and hence the girders are not placed exactly opposite one another. This, although it very much increases the span to be crossed, is frequently necessary with railway structures, to avoid the evil of short curves in the line of the rails. The angle of skew in this bridge is 63°; or, in other words, the direction of the bridge crosses the direction of the river at an angle of 63° instead of 90°, as would be the case if placed square across.

The Piers consist of a large massive foundation of masonry, sixty feet long by thirteen wide, formed in the shape of a cut-water at either end, and rising up with a slight batter; at a height of about ten feet, two hexagonal piers rise from each of these, the side of the

hexagon being about five feet. Upon each pair, one of the girders rests, at a height of forty feet above the water-level. The towers are carried up about sixty feet in all, and end with a turret, in agreement with the castellated abutments.

The Girders.—Fig. 71 is a cross section of one of the girders at the centre of the great span; Fig. 72 a plan of the bottom of one side girder and cross-beams, as they rest on the edge of the pier; Fig. 73, a plan of the top, and Fig. 74 a plan of the bottom. The girder is 11 feet 6 inches deep, and 2 feet 6 inches wide between the vertical or S plates. The length of each girder is 280 feet. Their transverse section is rectangular throughout; and both the sides and the top and bottom are parallel.

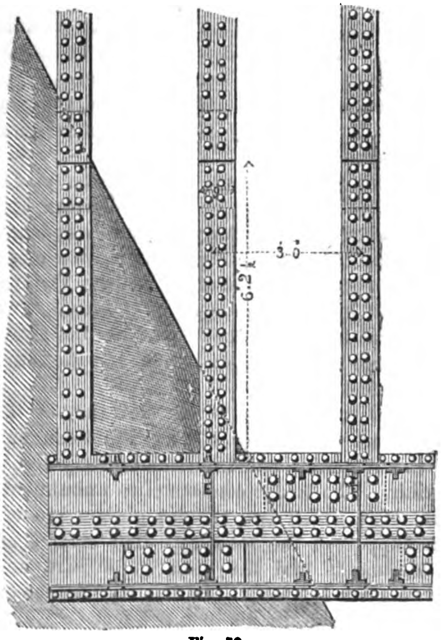


Fig. 72.

It is evident that in these girders the greatest strength to resist rupture is required in the middle of the span: hence, in the Britannia Bridge the top was made of a parabolic form, the depth of the tube decreasing from 33 feet at the centre of the Britannia Tower, to 22 feet 9 inches at the abutments. In these tubular girder bridges, however, the decrease of strength is generally effected in another way. The top and bottom are made parallel for the sake of simplicity of construction; but the thickness of the plates is diminished as they recede from the centre towards the ends.

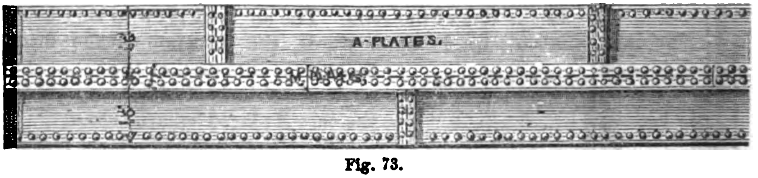


Fig. 73.

Fig. 71, which is a cross section of one girder, shows the arrangement of the material of which they are composed.

The Top is divided into two compartments or cells, by top and bottom plates AA and BB, and three vertical plates VV (Fig. 71). The A and B plates are 8 feet long by 1 foot 6 inches broad, so that two placed side by side make the width of the girder. They are $\frac{7}{16}$ inch thick at the centre, and decrease in thickness, so that towards the ends they are only $\frac{5}{16}$ inch thick. These plates are placed with their ends abutting against each other, and with the joint on one side opposite the middle of the plate on the other (Fig. 73). All the joints are secured by covering-plates both outside and inside, carefully riveted with $\frac{3}{4}$ inch rivets placed at distances of three inches apart. The vertical plates are connected with the A and B plates by angle-irons running the whole length of the girder, and riveted at distances of three inches throughout their length. The V plates are eight feet long, one foot two inches wide, $\frac{7}{16}$ inch thick in the middle, diminishing to $\frac{5}{16}$ at the ends of the girders. The angle-irons also vary from $3 \times 3 \times \frac{7}{16}$ to $3 \times 3 \times \frac{5}{16}$. These angle-irons very much increase the area of the top, and give great rigidity and power of resistance to compression.

Over the shorter spans the centre vertical plate is removed, so that there is only one cell, the strength not being required to be so great there as over the large span.

The Bottom of the girder (Fig. 74) is made of two thicknesses of plates, riveted together into a thick double plate, so as best to resist the tension to

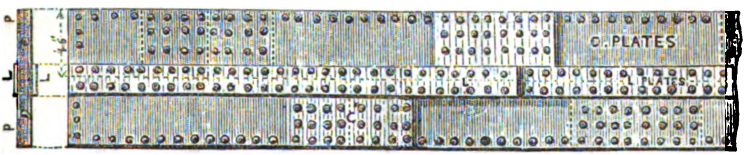


Fig. 74.—Plan and Section.

which it is subjected. The C plates which compose it are rolled to the extra length of twelve feet, in order that there may be as few joints as possible, and the bottom resemble one long unbroken sheet. The plates are each 1 foot 6 inches wide, and $\frac{12}{16}$ inch thick at the middle, diminishing to $\frac{5}{16}$ at the ends. The longitudinal joint is covered by L plates 12 feet by 7 inches, and diminishing in thickness in the same ratio as the C plates. The cross-joints, which are made to alternate, are secured by covering-plates above and below, each 2 feet 8 inches by 1 foot $2\frac{1}{2}$ inches. The position of the covering-plates and L plates is shown in Fig. 74.

The riveting of this part requires the greatest care, as otherwise the joints would materially reduce the strength of the bridge; the rivets are all one inch in diameter, and are placed at distances of four inches apart. Every covering-plate has twenty-four rivets, or twelve on each side of the joint, to ensure the connection of the parts. The tendency of the strain on the lower side of the tubes is to separate or open the joints, and on the upper side to force them closer together. It follows, therefore, that in the one case the plates should be most firmly bound together longitudinally; and in the other,

the ends should be butted against each other, and only such a covering-plate should be introduced as would prevent these ends buckling up and sliding past one another. The system of uniting the plates at the bottom of these bridges has been called *chain-riveting*, from the fact of the rivets being placed one behind the other, in the line of the length of the plates, giving them the appearance of a chain. The loss of the tensile strength of any plate weakened by the perforation of rivet-holes, is in exact proportion to the *transverse* sectional area punched out; and the saving of strength gained by the introduction of chain-riveting will be appreciated when it is stated, that the plates are only weakened by three holes across each plate, instead of six or eight, which would have been requisite had the old plan been followed.

The Sides of the girder are composed of large plates 10 feet $1\frac{1}{2}$ inches long by 2 feet broad; these are $\frac{6}{16}$ inch thick in the middle of the spans, and $\frac{7}{16}$ inch thick over the piers, in consequence of the strains upon them being greater at these parts. Their joints are covered on the outside by strips $4\frac{1}{2}$ inch $\times$ $\frac{4}{16}$ inch, and on the interior by ┬ irons $4\frac{1}{2} \times 3\frac{1}{2} \times \frac{9}{16}$. These ┬ irons give considerable rigidity to the tube, and are connected with the sides by $\frac{3}{4}$-inch rivets placed at distances of three inches apart. Over the piers

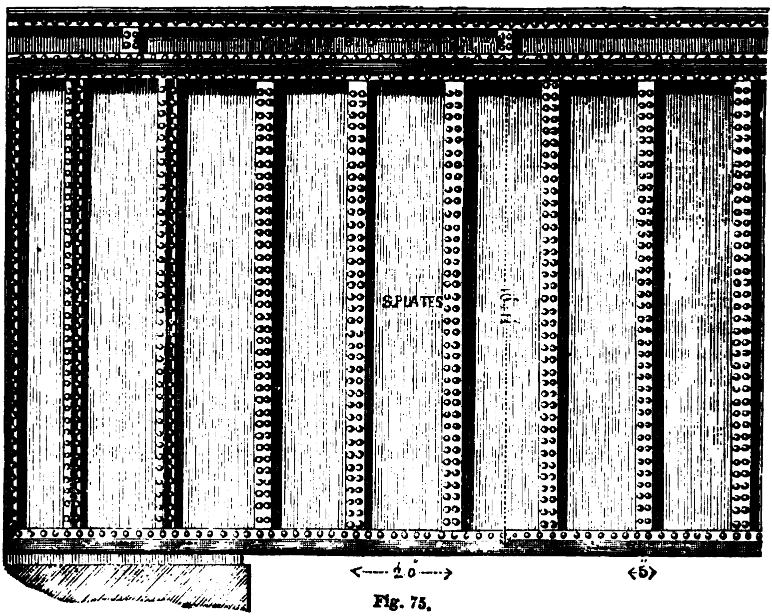


Fig. 75.

and abutments the outside covering-plates are replaced by ┬ irons. Fig. 75 is an elevation of the outside of the girder, showing the S and V plates, with the covering-strips, &c.

About the middle of the tube the small plates G, Fig. 71, are riveted to the opposite ⊤ irons on the interior of the tube. These serve to keep the girder in form, and prevent the sides bulging either way.

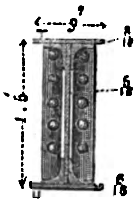


Fig. 76.

The Cross-beams.—To support the roadway, a series of wrought-iron cross-beams are stretched from one girder to the other, and over these is placed the longitudinal planking which supports the roadway. These cross-beams (section, Fig. 76) are composed of a vertical plate, X (Fig. 71) 1 foot 5 inches deep and $\frac{5}{16}$ inch thick, with two angle-irons at the top and at the bottom, over which a plate is riveted, so as to form a beam of the form shown in Fig. 17 (page 411). The plate at the top of these cross-beams is 9 inches wide and $\frac{8}{16}$ thick; that at the bottom 9 inches wide and $\frac{6}{16}$ thick. Two pieces of angle-iron are fixed at each end, by which they are riveted to the side of the girder, so as to rest on the ledge formed by the bottom angle-iron. These cross-beams are placed at distances of three feet apart.

Opposite the point where the cross-beams are riveted to the side of the girder, the plates marked E (Fig. 71) are introduced (being riveted to the opposite ⊤ irons), in order to throw the strain over the centre of the girder,

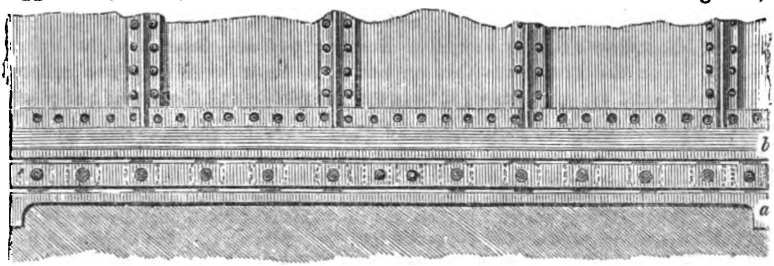


Fig. 77.

and prevent the load of the cross-beams pulling the girder out of the perpendicular. Fig. 72 exhibits the arrangement of the cross-beams close to the abutments, with a horizontal section of the girder.

One other provision remains to be noticed. A moment's consideration will show that even ordinary changes of temperature will produce a perceptible expansion in so large a mass of metal. It is computed that ordinary changes of temperature may produce a difference of length of as much as six inches in each of the Britannia tubes; and were not this provided against it would introduce a dangerous strain. In the present bridge the girders are fixed at the piers RR, WW (Fig. 69), on cast-iron bed-plates, the expansion between those points not being suffi-

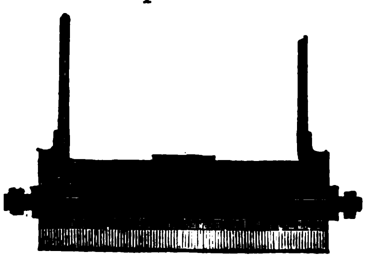


Fig. 78.

cient to render this arrangement dangerous; but on the other two piers there is an apparatus of rollers, which allows free motion backwards or forwards.

Figs. 77, 78, and 79 show this apparatus as arranged over the piers YY. Ten wrought-iron rollers are fixed in a frame which rests on a cast-iron bed-plate *a*; over them there is another cast-iron plate *b*, upon which the girder

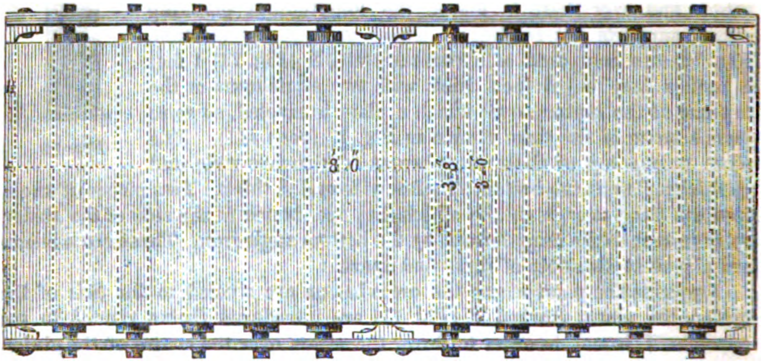


Fig. 79.

rests; the rollers are four inches in diameter, and are placed at eight inches apart. For the abutments this apparatus is made with only five rollers. Pieces of hard wood are inserted between the girder and the upper bed-plate.

Table showing the Proportions of Tubular Girder Bridges, from 30 to 150 feet span:—

Span.		Centre breaking-weight of bridge.	Sectional area of bottom of one girder.	Sectional area of top of one girder.	Depth of the girder in the middle.	
Ft.	Ins.	Tons.	Inches.	Inches.	Ft.	Ins.
30	0	180	14·63	17·06	2	4
35	0	210	17·06	19·91	2	8
40	0	240	19·50	22·75	3	1
45	0	270	21·94	25·59	3	6
50	0	300	24·38	28·44	3	10
55	0	330	26·81	31·28	4	3
60	0	360	29·25	34·13	4	7
65	0	390	31·69	36·97	5	0
70	0	420	34·13	30·81	5	5
75	0	450	36·56	42·67	5	9
80	0	480	39·00	45·50	6	2
85	0	510	41·44	48·34	6	7
90	0	540	43·88	51·19	6	11
95	0	570	46·31	54·03	7	4
100	0	600	48·75	56·88	7	8
110	0	660	53·63	62·56	8	5
120	0	720	58·50	68·25	9	3
130	0	780	63·38	73·94	10	0
140	0	840	68·25	79·63	10	9
150	0	900	73·13	85·31	11	6

Table showing the Proportions of Tubular Girder Bridges, from 160 *to* 300 *feet span* :—

Span.		Centre breaking-weight of bridge.	Sectional area of bottom of one girder.	Sectional area of top of one girder.	Depth of the girder in the middle.	
Ft.	Ins.	Tons.	Inches.	Inches.	Ft.	Ins.
160	0	960	90·00	105·00	10	8
170	0	1020	95·63	111·56	11	4
180	0	1080	101·25	118·13	12	0
190	0	1140	106·88	124·69	12	8
200	0	1200	112·50	131·25	13	4
210	0	1260	118·13	137·81	14	0
220	0	1320	123·75	144·38	14	8
230	0	1380	129·38	150·94	15	4
240	0	1440	135·00	157·50	16	0
250	0	1500	140·63	164·06	16	8
260	0	1560	146·25	170·63	17	4
270	0	1620	151·88	177·19	18	0
280	0	1680	157·50	183·75	18	8
290	0	1740	163·13	190·31	19	4
300	0	1800	168·75	196·88	20	0

The strength of the bridge over the Suir is computed as follows :—

The Large Span.

Sectional Area of the Top.

		sq. ins.
2 plates 36 × $\frac{7}{16}$	=	31·50
3 do. 14 × $\frac{7}{16}$	=	18·38
2 longitudinal plates 7 × $\frac{7}{16}$.	=	6·13
10 angle-irons 3 × 3 × $\frac{7}{16}$ . .	=	26·25
		82·26

Sectional Area of the Bottom.

2 plates 36 × $\frac{12}{16}$	=	54·00
2 longitudinal plates 7 × $\frac{12}{16}$.	=	10·50
2 angle-irons 3 × 3 × $\frac{12}{16}$ . .	=	9·00
		73·50

Therefore by formula, $W = \frac{adC}{l}$,

$$\frac{73{\cdot}5 \times 138 \times 80}{1800} = \overset{\text{Tons.}}{450{\cdot}8} = \text{centre breaking-weight of one main girder.}$$

1803·2 = breaking weight of large span, load equally distributed.
12·21 = ditto per lineal foot.

Similarly we find for the small spans :—

		sq. ins.
Sectional area of the top .	=	51·25
" " bottom .	=	30·63

$$\frac{30{\cdot}63 \times 138 \times 80}{600} = \overset{\text{Tons.}}{563{\cdot}59} = \text{centre breaking-weight of one main girder.}$$

2254·36 = breaking-weight of small span, load equally distributed.
45·11 = ditto per lineal foot.

The above may serve as an example of the manner in which the strength of all bridges of this class is calculated, and the formula $W = \frac{adC}{l}$ may be regarded as sufficiently accurate for all practical purposes. We may observe in explanation, that W is the weight which, placed upon the centre between the supports, would break the girder. Twice this, or 2W, is, therefore, the weight which placed in the centre would break both girders; and 4W the weight which would break both girders, if it were distributed *uniformly* over their whole surface: 4W divided by the span in feet gives the strength of the bridge per lineal foot. Further, the formula only applies to girders in which the area of the top bears a proportion of at least 12 : 11 to the area of the bottom.

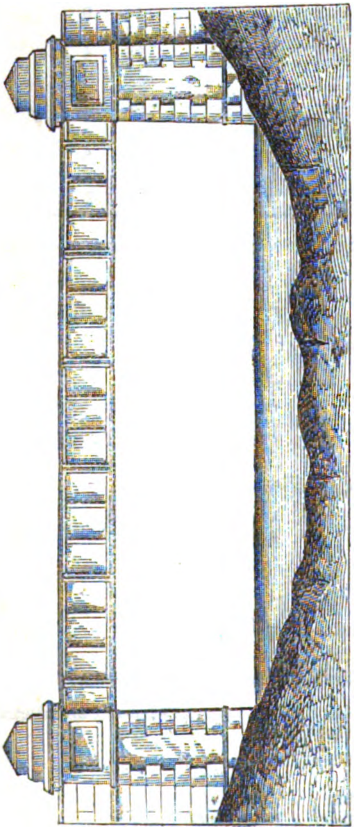


Fig. 80.

Plate Bridges.—For small spans not exceeding sixty or seventy feet, the tubular arrangement is frequently laid aside, and the girder constructed in the form of a simple beam. We have already alluded to this point, and have only to add an example of the manner in which plate beams are applied to bridges.

The great cause affecting the durability of iron bridges is oxidation, arising from a damp atmosphere; and if precautions were not taken, there is reason to believe that this would be productive of disastrous results. To obviate this defect, tubular and tubular girder brides are designed, so that access may be gained to every part for the purpose of painting. Thus, for instance, the cells of the Britannia Bridge and of the Suir Bridge are sufficiently large to admit a man or a boy. But in bridges of small span this cannot always be provided for; and hence the superiority of a plate girder. Simplicity of construction and cheapness are also great advantages of this form, which more than compensate for some loss of strength.

Fig. 80 is an elevation and Fig. 81 a cross section of one girder of a plate bridge of 50 feet span. It consists of two girders, each 57 feet long and 4 feet 6 inches deep. The plates forming the top are 6 feet long by 1 foot 6 inches

wide, and $\frac{14}{16}$ thick in the middle of the span. The joints are covered with strips 1 foot 6 inches by 5 inches, by $\frac{9}{16}$ inch thick. The bottom is composed of plates 12 feet by 1 foot 6 inches, carefully chain-riveted; the sides of plates 3 feet by 4 feet $4\frac{1}{2}$ inches, and $\frac{9}{16}$ inch thick at the centre of the span, and $\frac{7}{16}$ thick at the abutments. The vertical side plates are connected with the top and bottom plates by angle irons $4 \times 4 \times \frac{10}{16}$. To give the girder sufficient rigidity to prevent lateral flexure, every third covering strip connecting the vertical side plates is replaced by a thick ┳ iron, composed of two angle irons (each 6 inches $\times$ 3 inches $\times \frac{9}{16}$ inch thick) riveted back to back.

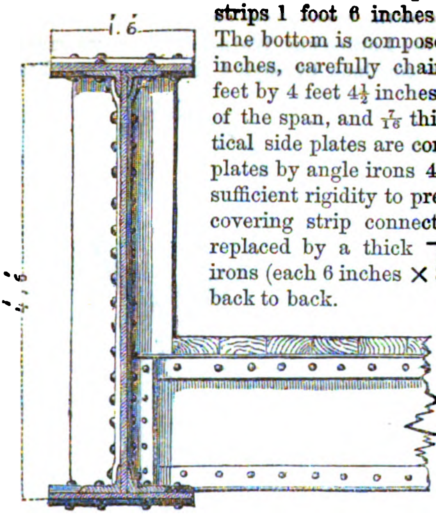


Fig. 81.

The roadway is supported on cross-beams riveted to the side plates, and placed at distances of 3 feet apart. The weight of iron in the bridge is about $29\frac{1}{4}$ tons.

As these are not so strong as the tubular girders, the constant C in the formula,

$$W = \frac{adC}{l}$$

is taken = 75 instead of 80 as before. Hence in this bridge,

Sectional area of top	=	25·750 inches.
„ „ bottom	=	22·375 „
Centre breaking-weight, or W	=	$\frac{22{\cdot}375 \times 54 \times 75}{600} = 151$ tons.
Breaking-weight of span, load equally distributed	=	604 tons.
Do. per lineal foot	=	12·08 tons.

Figs. 82 and 83 show two modifications of the tubular and plate girder which have been adopted by some engineers; but though of a form admirably adapted for securing the greatest strength with a given weight of material, they are of a more complex form, rather more expensive, and liable to corrosion.

In these very important constructions we might give a greatly increased number of examples, both as regards form and the objects to which they are applied; but within our circumscribed limits this cannot be accomplished, and we are, therefore, reluctantly compelled to forego any further description of entirely new developments, which have enabled the engineers of the present day to accomplish what was only a few years since considered a perfectly Utopian project. Now, wide rivers, deep ravines, and valleys, are bridged over with solid unyielding structures of several hundred feet span, supporting

rolling loads of several hundred tons in weight at a velocity considerably beyond that of the bounding deer or the fleetest race-horse.

Other constructions, such as the Lattice and Warner Bridges, we cannot touch upon, and must therefore conclude by saying that they have been

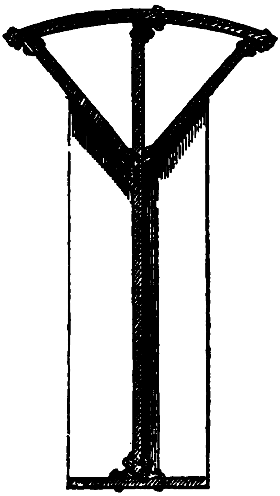


Fig. 82.

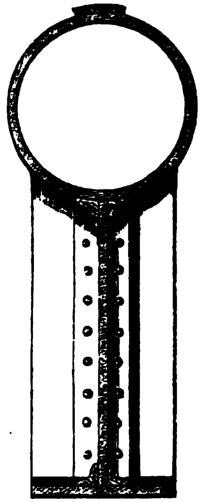


Fig 83.

greatly improved since the introduction of the tubular and tubular girder bridges; in fact, they are neither more nor less than the tubular girder with lattice or open sides, and the top and bottom proportioned on the same principle, as deduced from the experiments and as given in the formula for that principle of construction, care being taken to reduce the constant for the lattice bridge from 80 to 75.

CHAPTER XXIII.

ON THE APPLICATION OF IRON TO SHIP-BUILDING.

THERE is probably no branch of industry in which the use of iron is more important than that of ship-building. The strength, ductility, and comparative lightness of this material are all in its favour; and, although much has been done in the application of iron to this important purpose, a great deal more remains to be accomplished.

Vessels composed of iron plates have been employed for more than fifty years in the navigation of canals; but it is not more than twenty-five or twenty-six since they were first introduced as sea-going vessels. It is true that the late Mr. Aaron Manby projected an iron vessel in 1820, which was built in the ensuing year, and early in 1822 was navigated by Captain (now Admiral Sir Charles) Napier from London to Havre, and on to Paris; this, however, was not a sea-going vessel, but an iron steamer constructed for the Seine, and which for many years navigated that river between Paris and Rouen.

From this period little appears to have been done in furtherance of the application of iron to the construction of ships till 1829-30, when the introduction of a new system of traction at high velocities on canals led to new developments; and from this time to the present, iron, as a material for ship-building, has been extensively used, and is increasingly in demand. From 1829 to 1832, iron ship-building may be considered to have been experimental; and the trials conducted by Mr. Fairbairn on the Forth and Clyde Canal,* simultaneously with those of Mr. John and Mr. McGregor Laird at Liverpool, led to a new era in the history of ship-building.

Among the first iron vessels for sea-going purposes was one of small tonnage, built at Manchester for the Forth and Clyde Canal Company. She was built with paddle-wheels on the quarter near the stern, and propelled by two high-pressure engines of, collectively, 30 horse-power. This vessel attained great speed, considering the date at which she was built; and for many years traded between Grangemouth and the coast of Fife, round to Dundee.

Previously to the building of the "Manchester," another small vessel, called the "Lord Dundas," was constructed for the same company. She was strictly experimental, and was propelled by a locomotive engine of 16 horse-power, with 8-inch cylinders. Such was the lightness of her construction, that the plates were only 1-14th of an inch thick, riveted to light T iron, which formed the ribs of the hull. This vessel had stern paddles, and was of the following dimensions:—

* Vide "Remarks on Canal Navigation," by W. Fairbairn. Longman, 1831.

Length, 68 feet.
Breadth on beam, 11 feet 6 inches.
Depth, 4 feet 6 inches.
Diameter of paddle-wheel, 9 feet.
Whole weight, including engine, paddle-wheel, &c., 7 tons 16 cwt.
Draught of water with cargo on board, 16 inches.

The "Lord Dundas" was built in 1830, conveyed through the streets of Manchester on trucks, and launched into the Irwell, where numerous trials took place in regard to her speed in narrow channels, such as canals; including such other direct experiments as were likely to result from vessels of this kind propelled by steam. Subsequently to these trials she was navigated to Liverpool, and from thence to Glasgow *viâ* the Isle of Man. As this voyage was rather a perilous one, when the slightness of the vessel's build and the thinness of her sheathing-plates are considered, and as it was among the first—if, indeed, it were not the very first—which indicated the necessity of adjusting the compass in order to neutralize the local attraction of the material by which it was surrounded, we may probably be permitted to give a brief narrative of the circumstances as they occurred during the voyage. The "Lord Dundas" sailed from Liverpool at four A.M. on a fine morning in June, 1831, and steered direct for the floating-light. She made the light in good time, notwithstanding a thick haze in the atmosphere, which, during the forenoon, thickened into a dense fog. Towards one o'clock land was descried upon the starboard bow, showing apparently that she had made considerable deviation in a westerly direction. A dispute arose as to what land it was—one party contending that it was the western side of the Isle of Man; the other, better acquainted with that side of the island, that it was not. After a considerable contest and examination of the charts, it was at last discovered that the little vessel was on the north of Morecambe Bay, approaching the coast of Cumberland. On the discovery of this error, and in consequence of the frail bark showing symptoms of weakness, from the effects of the swell which was rolling in from the west, it was considered desirable to look out for shelter; and consequently her course was altered in the direction of the Island of Peel Foundry, where she was sheltered for the night. On the following morning she crossed to Ramsey, where the question of the variation of the compass was investigated, and rectified by the simple process of nailing a block of iron to the deck, in the immediate vicinity of the compass—by this means neutralizing the local attraction of the iron by which it was surrounded. After this, the remainder of the voyage from Ramsey to Greenock was effected in a direct course with perfect safety.

We have noticed these circumstances as illustrating the imperfect state of our knowledge, as respects the influence of large masses of iron upon the ship's compass. It has been ascertained that the angle-iron and T iron ribs, when carried above the deck so as to form part of the bulwarks, had a remarkable effect upon the compass, each of them forming, as it were, a separate magnet, whose influence, unless neutralized by some greater magnetic power, caused a considerable deviation of the needle, so that it indicated

a point wide of the magnetic north; and as this deviation altered with every change of the position of the vessel, no reliance could be placed upon it. Captain Johnson and Professor Airey, by an interesting series of experiments, ultimately settled this question, and provided a remedy in the adjustment and correction of the compass on board of iron ships.

The object contemplated by this light vessel and light machinery was, to ascertain how far quick speeds could be attained upon canals by steam-power. As much as fourteen miles an hour had been accomplished by horses, with a tractive power of 352 lbs. by dynamometer, and that without the least appearance of surge;* but the experiments made with the "Lord Dundas" steamer indicated a very different law, and, under the most favourable circumstances, never exceeded more than eight to eight and a half miles an hour, and that with an enormous swell washing over the banks of the canal in every direction. In fact, the object for which the boat was built was never attained, and it was found impossible to effect by steam what was done by horses. It nevertheless led to a more important and a greatly-enlarged branch of industry—namely, the construction of iron vessels upon a large scale for ocean traffic.

These experimental vessels, the "Lord Dundas" and the "Manchester," already mentioned, in conjunction with the "Alburka," and some other vessels, by Messrs. J. Laird and Co., of Liverpool, may be considered as the first successful attempts in iron ship-building. Shortly after the completion of these vessels, several large establishments were founded for this branch of construction, amongst whom may be enumerated Messrs. W. Fairbairn and Co., Millwall, and Messrs. Ditchburn and Mare, Blackwall, London; Messrs. Laird and Co., Liverpool; Messrs. Tod and McGregor, Glasgow; and several others, all of whom were engaged for many years in the construction of iron ships.

In this chapter we shall be unable to go much into detail, and must confine ourselves to a few general observations in connection with the more important application of iron as a material of construction for ocean steamers and sailing vessels, exposed to all the changes and vicissitudes of wind and tides in the open sea.

Fig. 84 exhibits a half cross section of one of Her Majesty's frigates of the second class, and will, to a certain extent, illustrate the principles of construction. It will be seen that the iron-ship is composed of a series of frames or ribs, placed at various distances apart; these are connected together in the interior of the vessel by transverse beams, mostly of iron, but sometimes of wood, which support the decks. Over the exterior of the ribs the iron sheathing-plates are riveted, so as to form a continuous water-tight covering over the entire exterior of the vessel.

Ribs.—One of the ribs is shown at *a a a*, Fig. 84; and its section will be seen in Fig. 85, which is a longitudinal section through the line *b b*; it consists of a vertical plate *c*, to which two angle-irons are riveted, one at the top and the other at the bottom. On the lower angle-iron the sheathing-

* "Remarks on Canal Navigation," page 57.

plates *d* are riveted; and on the upper, interior plates, some of which in large vessels are riveted diagonally, so as to form stringers and braces from the keelsons round the bilge to the upper decks. These ribs are placed at distances of about fifteen inches to eighteen inches apart, according to their position in the direction of the length of the ship.

Other kinds of frames might be used with double angle-iron, as shown at *e e*, in the annexed sketch (Fig. 86), but they are more expensive; and from the increased complexity of construction, the extra strength obtained does not compensate for the difference of cost. Altogether the frames shown in Fig. 85 have come into general use as the most effective and easy of construction.

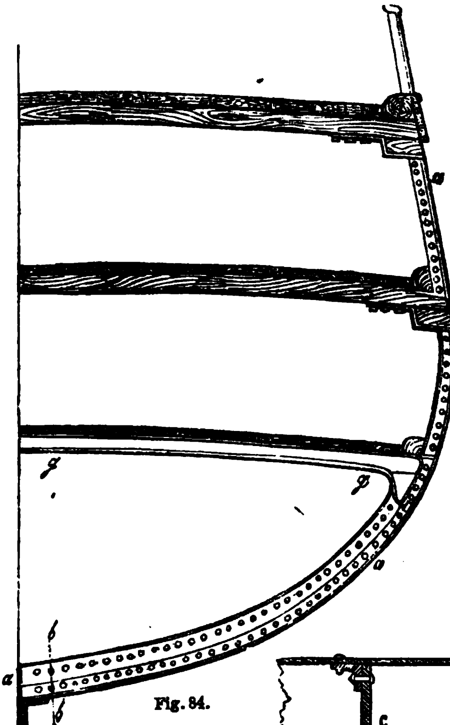


Fig. 84.

Keels.—This part of the vessel requires to be made exceedingly strong to resist the pressure or violent shocks to which it is subjected, when a vessel grounds.

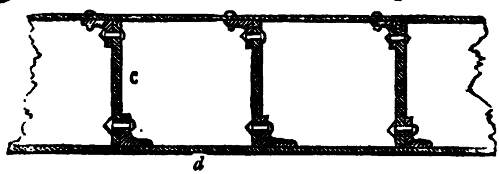


Fig. 85.

It is made in various ways, generally with a false keel, which is riveted on below the ribs by two angle-irons. The false keel is intended to receive the first shock in grounding; and is so arranged that it may even be carried away without material injury to the true keel.

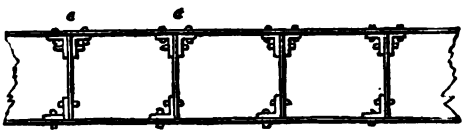


Fig. 86.

Fig. 87 shows a method in which it will be seen that the sheathing-plates *a a* are bent downwards so as to grasp the side of the keel, which consists of a massive plate of iron; whilst the angle-iron of the ribs is bent upwards at right angles, and is firmly riveted to the vertical keel plate.

Decks.—The floorings are supported upon beams extending from one side of the vessel to the other, and attached at either end to the ribs or side

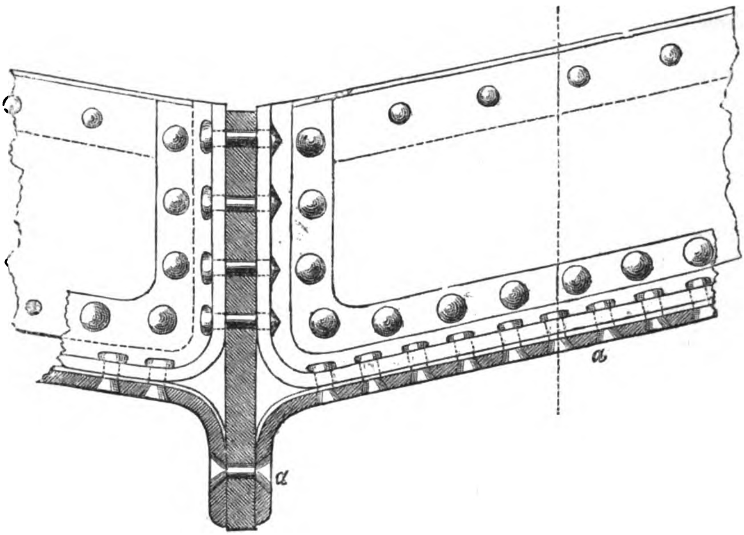


Fig. 87.

frames. In the section, Fig. 84, the two upper decks are supported upon wooden beams, as in an ordinary wooden vessel; but wrought-iron beams may be substituted for these with great advantage, as shown at *g g*.

Fig. 88.

These deck-beams have been made of various forms, the best of which for large vessels is probably that shown in Fig. 88, which consists of angle-irons riveted to the top and to the bottom of a thin vertical plate. In some cases a vertical plate, with two angle-irons at the top and one at the bottom, is used, and has the advantage of greater simplicity, though the material is not so well distributed. The box beam (Fig. 89) is employed for supporting the shafts and paddle-boxes of steamers, &c.

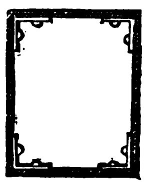


Fig. 89.

Riveting of the Plates.—In all wrought-iron constructions, the mode of joining two plates together is the same. When the article can neither be produced at once from the rolling mill nor the steam-hammer, and except in the comparatively few cases where parts are *welded* together, they are universally united by *rivets*. A series of holes being made through both pieces, a small bolt, with a head upon one side, is passed through each, and then quickly hammered down on the other side to another head, so as to

grasp the parts tightly between them. These rivets are usually employed in a red-hot state, both because they are then more easily hammered down, and because in cooling they contract and draw the parts together with great force.

Since the introduction of this process, the greatest improvement has been the substitution of the riveting-machine, invented by Mr. Fairbairn; by means of which the object is secured in considerably less time and at less cost, and which completes the union of the plates with much greater perfection than could possibly be done by the hand. But this new and very superior process has not as yet been successfully applied to the riveting of plates for ships.

On comparing the strength of plates with their riveted joints, it will be necessary to examine the sectional areas taken in a line through the rivet-holes with the section of the plates themselves. It is perfectly obvious that in perforating a line of holes along the edge of a plate, we must reduce its strength; it is also clear that the plate so perforated will be to the plate itself, nearly as the areas of their respective sections, with a small deduction for the irregularities of the pressure of the rivets upon the plate; or, in other words, the joint will be reduced in strength somewhat more than in the ratio of its section through that line to the solid section of the plate. For example, suppose two plates, each two feet wide and three-eighths of an inch thick, to be riveted together with ten ¾-inch rivets. It is evident that out of two feet, the length of the joint, the strength of the plates is reduced by perforation to the extent of seven and a half inches; and here the strength of the plates will be to that of the joint as 9 : 6·187*, which is nearly the same as the respective areas of the solid plate and that through the rivet-holes; or as 24 : 16·5†. From these facts it is evident that the rivets cannot add to the strength of the plates, their object being to keep the two surfaces of the lap in contact. It may be said that the pressure or adhesion of the two surfaces of the plates would add to the strength; but this is not found to be the case to any great extent, as in almost every instance the experiments indicate the resistance to be in the ratio of their sectional areas.

When this great deterioration of strength at the joint is taken into account, it cannot but be of the greatest importance that in structures subjected to such violent strains as ships, the strongest method of riveting should be adopted. To ascertain this, a long series of experiments were undertaken by Mr. Fairbairn, some of the results of which will be of interest here. The joint ordinarily employed in ship-building is the *lap-joint*, shown in Figs. 90 and 91. The plates to be united are made to overlap, and the rivets are passed through them, no covering-plates being required, except at the ends of the plate where they butt against each other. It is also a common practice to countersink the rivet-heads on the exterior of the vessel, that the

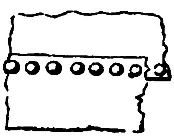


Fig. 90.

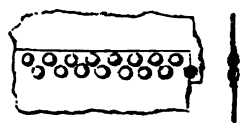


Fig. 91.

* The ratio of the areas. † The ratio of the breadth of metal.

hull may present a smooth surface for her passage through the water. This system of riveting is shown in Fig. 87, where the rivets of the sheathing-plates are countersunk. This system of riveting is only used when smooth surfaces are required; under other circumstances their introduction would not be desirable, as they do not add to the strength of the joint, but to a certain extent reduce it. This reduction is not observable in the experiments; but the simple fact of sinking the head of the rivet into the plate, and cutting out a greater portion of metal, must of necessity lessen its strength, and render it weaker than the plain joint with raised heads.

There are two kinds of lap-joints, those said to be single-riveted (Fig. 90) and those which are double-riveted (Fig. 91). At first the former were almost universally employed, but the greater strength of the latter has since led to their general adoption in the larger descriptions of vessels. The reason of the superiority is evident. A riveted joint gives way either by shearing off the rivets in the middle of their length, or by tearing through one of the plates in the line of the rivets. In a perfect joint the rivets should be on the point of shearing just as the plates were about to tear; but in practice the rivets are usually made slightly too strong. Hence it is an established rule to employ a certain number of rivets per lineal foot. If these are placed in a single row, the rivet-holes so nearly approach each other that the strength of the plates is much reduced; but if they are arranged in two lines, a greater number may be used, and yet more space left between the holes, and greater strength and stiffness imparted to the plates at the joint.

The results of Mr. Fairbairn's experiments upon the two forms of joint are given in the following summary:—

	Cohesive strength of plates. Breaking-weight in lbs. per sq. in.	Strength of single-riveted joints of equal section to the plates, taken through the line of rivets. Breaking-weight in lbs. per sq. in.	Strength of double-riveted joints of equal section to the plates, taken through the line of rivets. Breaking-weight in lbs. per sq. in.
	57,724	45,743	52,352
	61,579	36,606	48.821
	58,322	43,141	58,286
	50,983	43,515	54,594
	51,130	40,249	53,879
	49,281	44,715	53,879
	43,805	37,161	
	47,062		
Mean	52,486	41,590	53,635

The relative strengths will therefore be—

For the plate 1000
Double-riveted joint. 1021
Single-riveted joint 791

From the above it will be seen that the single-riveted joints have lost one-

fifth of the actual strength of the plates, whilst the double-riveted have retained their resisting powers unimpaired. These are important and convincing proofs of the superior value of the double joint; and in all cases where strength is required, this description of joint should invariably be used.

Comparing these results with those of a former analysis, we have—

	1000 : 1021 and 791*	
	1000 : 933 and 731	
Mean . . .	1000 : 977 and 761	

which in practice we may safely assume as the correct value of each. Exclusive of this difference, we must, however, deduct thirty per cent. for the loss of metal actually punched out for the reception of the rivets; and the absolute strength of the plates will then be, to that of the riveted joints, as the numbers 100, 68, 46. In some cases, where the rivets are wider apart, the loss sustained is, however, not so great; but in boilers and similar vessels where the rivets require to be close to each other, the edges of the plates are weakened to that extent. Taking into consideration the various circumstances affecting the experimental results, we may fairly assume the following relative strengths as the value of plates with their riveted joints.

Taking the strength of the plate at	100
The strength of the riveted joint would then be .	70
And the strength of the single-riveted joint . .	56

Wood and Iron as Materials for Ship-building.—We shall consider this point under three heads—

STRENGTH,
DURABILITY,
ECONOMY.

To ascertain the superiority of iron over wood in regard to strength, let us consider the strains to which a vessel is subjected. Let us take, for example, a vessel of similar dimensions to the "Great Western" (the first steamer that successfully crossed the Atlantic), 212 feet long between the perpendiculars, 35 feet beam, and 23 feet from the surface of the main-deck to the bottom of the sheathing attached to the keel. Now, considering a vessel of this magnitude, with its machinery and cargo, to weigh 3000 tons, including her own

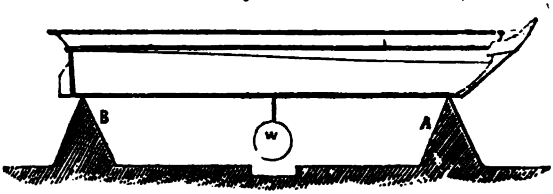


Fig. 92.

* The cause of the increase of strength in the double-riveted plates may be attributed to the riveted specimens being made of best iron; whereas the mean strength of the plates is taken from all the irons experimented upon, some of inferior quality, which will account for the high value of the double-riveted joint.

weight; and supposing, in the first instance, that she is suspended upon two points, A and B, resting on the bow and stern, at a distance of 210 feet, as shown in Fig. 92; we should then have to calculate, from some formula yet to be determined by experiment, the ultimate strength of the ship.

To determine this formula with accuracy is a work of research. In the meantime, we are fortunate in having before us that which applies with so much certainty to tubular bridges and tubular girders; and all that is required in this case will be to ascertain the correct sectional area of the plates, to prevent the tearing asunder of the bottom, and the quantity of material necessary to resist the crushing force along the line of the upper-deck on the top. It is true that the necessary data have yet to be determined; but the iron ship-builder cannot be far wrong if he assume the weight W in the middle (Fig. 92) to be equal to the united weights of the ship and cargo. This, in the case before us, would give an ultimate power of resistance of 3000 tons in the middle, or 6000 tons equally distributed along the ship, with her keel downwards.

Assuming these tests, or the calculations derived therefrom, to be correct, let us now bring the vessel into a totally different position, as in Fig. 93, having the same weight of cargo on board, and supported by a wave, which, for the sake of illustration, we may consider as supporting the vessel upon a single point in the middle.

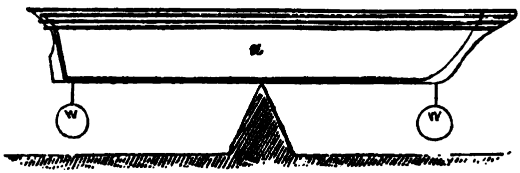


Fig. 93.

In this position we find the strain reversed; and in place of the lower part of the hull of a ship being in a state of tension, it is, on the contrary, in a state of compression, and the whole of those parts below the neutral axis are subjected to that strain. On the other hand, the upper part is in a state of tension; and that tension, as well as the compressive strain below, will be found to vary in degree in the ratio of the distances from the centre of the neutral axis *a* (Fig. 93), round which the forces of tension and compression revolve. In this supposed position we may venture to calculate the strengths, in order to ascertain the limit or maximum of security, and act as if the vessel were placed in trying circumstances,—either contending with the rolling seas of a hurricane, or suffering the actual suspension of either portion when taking the ground. In these critical positions we arrive at the conclusion, that calculations founded upon the formula for wrought-iron tubular beams will determine the strength and resisting powers of an iron ship, and that under every contingency and every circumstance in which the vessel can be placed. Moreover, it will give a wide margin of security under all those forms and conditions of peril to which every vessel navigating the ocean is exposed. We are fully aware that many thousand vessels are now afloat, that would not stand one-third of the tests which

we have taken; but that is no reason why we should not endeavour to effect more judicious distribution of the material, in order to attain the maximum strength, where human life and the fortunes of the public are at stake.

To show that we have not selected tests which no vessel would stand, we append the following incidents:—

In hauling an iron steamer of nearly 400 tons burthen out of a temporary basin, she grounded on the extreme end of the bank, and was left, as the tide receded, with forty feet of her stern entirely without support, and her bow buried in the opposite bank. On the return of the tide, the vessel floated, and immediately afterwards she proceeded on her voyage.

A large steamer, the "Vanguard," ran foul of a reef of rocks on the west coast of Ireland, and continued exposed to the swell of the Atlantic beating her upon them for several days with comparatively little injury, excepting only the corrugation of the plates along her bottom. She appears to have rested upon a number of small hard rocks from the stem to the full part of the vessel just under the paddle-wheels, and from that part to the stern to have been quite unsupported, except at one place where the keel was broken. Mr. Clark, who went to examine her, states that, "although she was beating hard for so many days, no part of her engines was deranged. Her engines were kept constantly at work, and, in his opinion, are now in as permanent working order as ever they were. Had the 'Vanguard' been built of wood instead of iron, she could not have been saved."

"The 'Royal George,' one of the iron steamers running between Liverpool and Glasgow—a vessel of unusual length in proportion to her beam—got on a rock near Greenock at high-water, when loaded with about 150 tons of dead weight besides her engines and coals, and was left there high and dry during a whole tide, without sustaining any injury. She rested nearly on her centre; and all who saw her were of opinion that no timber vessel could have remained in that position without breaking her back."*

We might adduce numerous other instances in which iron vessels have, without material injury, stood the strains which must have caused a timber vessel to go to pieces. An iron ship is united by riveting into a single firm mass; whilst a wooden vessel is composed of an innumerable number of pieces, all imperfectly joined together, but which are, nevertheless, dependent on each other for support; so that if any one gives way, the stability of all the rest is endangered.

In his paper on iron as a material for ship-building, Mr. Fairbairn gives the following results of some experiments on the comparative strength of wood and iron, when subjected to pressure from a blunt instrument placed at right angles to the surface of the plate. It will be seen that, in these experiments, an endeavour was made to place the material in circumstances similar to those mentioned above, where the vessel is beating upon hard and

* Grantham "On Iron as a Material for Ship-Building."

unequal ground. In these experiments, the wrought-iron plates were fastened upon a frame of cast-iron, one foot square inside, and one foot six inches outside. The sides of the plate, when hot, were twisted round the frame, to which they were firmly bolted. The force to burst it was applied in the centre by a bolt of iron, terminating in a hemisphere three inches in diameter.

Summary of Results.

	lbs.	Mean: lbs.
In Experiment I., a plate one-fourth of an inch thick was burst by	13,789	16,779
In Experiment II., a plate one-fourth of an inch thick was burst by	19,769	
In Experiment III., a plate half an inch thick was burst by	37,519	37,723
In Experiment IV., a plate half an inch thick was burst by	37,928	

Here the strengths are as the depths, a half-inch plate requiring double the weight to produce fracture that had previously burst a quarter-inch plate.

The experiments on wood were made upon good English oak, of the same width as the iron plates. The specimens were laid upon solid planks twelve inches asunder, and by the same apparatus the rounded end of the three-inch pin was forced through them.

Summary of Results.

	lbs.	Mean : lbs.
Strength of planks 3 inches thick	18,941	17,933
" " 3 " "	16,925	
" " 1½ " "	4,532	4,406
" " 1½ " "	4,280	

Here the strength to resist crushing follows the ratio of the square of the depth, as is found to be the case in the transverse fracture of rectangular bodies of constant breadth and span. The experiments show conclusively the superiority of iron in ordinary cases.

Durability.—The durability of iron ships is now established beyond a doubt; and it is generally admitted that they remain fit for service longer than those of timber. At first it was thought that the action of salt-water would cause a rapid oxidation, and very soon disable them; indeed, oxidation has been the rock-ahead of every iron ship for the last twenty-years. The evil has been exaggerated; and there are instances of iron ships built twenty years ago, which are still in existence with no sensible appearance of corrosion or decay, and, what is of equal importance, without having required repairs, if we except a few coats of oil-paint, or the application of some other anti-corrosive substance to neutralize the effects of the sea-water. Nature, however, comes to our assistance in this, as in almost every other attempt in the constructive arts, and seems to confirm the proverb, "A bright sword never rusts;" for it is with iron ships as with iron rails—when in constant use there is little, if any, appearance of oxidation.

Economy.—Mr. Grantham, in the work already quoted, comes to the conclusion that iron vessels are on the whole less expensive in construction than similar vessels of wood. But assuming that, when built in the best manner, they cost about the same; still, the iron ship has great advantages. The strength of iron is so great that we are enabled to use a much thinner shell than with wood; and hence there is much more stowage room. The cost of maintaining an iron vessel, repairs, &c., are very small; whilst in a timber vessel they amount to a large sum. Iron vessels are not subject to a dry rot; and we have already seen that they will remain under severe strain comparatively uninjured, when a timber vessel would go to pieces.

In concluding this chapter, it will be necessary to advert to the use of iron as applied to vessels of war. There cannot exist a doubt as to the advantages to be derived from iron as a material for ship-building, and it is probably as desirable in the Royal Navy as in the Merchant Service; but the great drawback to its application is the effect of shot upon iron plates, and the consequent danger to the safety of the vessel from this cause. This danger does not arise so much from point-blank shot entering the ship at high velocities, as from shot ranging from a distance, and which strike the vessel with a reduced force. In the first case the shot penetrates and passes through the plates, making a perforation equal in diameter to the shot; but a half-spent shot when it arrives, not only penetrates the side of the ship, but tears up the plates to a distance of some feet on every side. It is from this that the chief danger is to be apprehended; and however serious the effects of the jagged splinters of iron may be when dispersed over the deck among the crew, it is, at the same time, a less evil than the entire loss of the ship. Such are the objections and drawbacks to the use of iron in the Navy; but the experiments on this subject, though to some extent conclusive in their results, were certainly not of that character to cause the entire abandonment of iron in the construction of vessels of war. In the settlement of this question much has yet to be done; but the time is probably not far distant when we may see the powerful armaments of Great Britain pouring forth upon her enemies missiles of destruction from the sides of iron ships.

CHAPTER XXIV.

MR. VOSE PICKETT'S NEW SYSTEM OF IRON ARCHITECTURE.

The ingenious and tasteful designs exhibited by Mr. Vose Pickett some fourteen years back, attracted at the time much attention to the subject of the application of iron, and other materials which he proposes to combine with it, for the purposes of architectural ornament; and it is to be regretted that he has not obtained the means of testing his system, by applying it practically on a scale of sufficient magnitude. To us the subject seems too important to be passed over; and we willingly allow Mr. Vose Pickett access to our pages, to explain the principles which he proposes to develop in his new system of iron architecture. Mr. Pickett states as follows :—

In the year 1842, the Royal Institute of Architects awarded their prize for an essay "On the Effects which should result to Architectural Taste, with regard to Arrangement and Design, from the general introduction of Iron in the Construction of Buildings." It is now from fourteen to fifteen years since the effort was made by the Institute, and also from the time when the writer was engaged in foreshadowing some of the essential grounds of this great question.

Genuine iron architecture, with its analogous materials, glass, slate, &c., will give to the world great advantages over those which the constructive mixture of iron with brick can ever be brought to afford; in fact, brick is here a wasteful and clumsy intrusion. Though nothing can be more totally different than "iron architecture" and the "use" of iron in architecture, yet it must ever be borne in mind that architects and architecture are often limited by circumstances; and there are occasions when the use of iron with brick is a necessity. The subject, as laid down by the writer in his various publications, resolves itself into three divisions :—

First.—The greatest and by far most important branch is genuine iron architecture; by which only can the advantages of building and architecture be carried to their utmost perfection. Here there must be no mixing of iron with brick.

Second.—The (suggested) iron law in architecture, or an improved use of iron with brick; which is necessary, seeing that ancient cities, and existing stone and brick buildings, have to be dealt with.

Third.—A new metallic art, and architecture for monuments and gold and silver structures; which does not require our consideration at present.

It is thus obvious that, inasmuch as the nature and essence, the powers and capacities of the materials proposed, are not only infinitely more enlarged, but of a totally opposite character to those of stone and brick; as the

principles of the ancient system all tend to develop the properties of stone and brick, and as the modern world is called upon to use and adapt, in the like and analogous manner, the powers of iron, &c.; and as the very first primary constructive principle demanded in metal is the very reverse of that employed in constructions of brick and stone; so all the associative principles of form and appliance must be of a different character also.

In resolving the elements of masonic architecture into first principles of form and feature, they are found to be four in number, which, as general principles, constitute alike the universal basis of every order or style.

The first consists of the solid wall, composed of blocks of stone, &c., piled upon each other.

The second, in surface-carved or relievo ornamental forms.

The third, in the use of piers and columns for the support of roofs and porticos; and

The fourth, in the universal prevalence, more or less, of angles and straight-lined forms.

These principles, being incompatible with the right use and just expression of metallic powers in architecture, require equivalents in the new or metallic system, which will be found in the six following primary principles:—

First Primary Principle.—Canister or hollow iron walls, with cast, chased, or repouse-work ornamental surface, in substitution of the solid wall and ashlered surface used in masonry. This includes glass, slate, or any other appropriate panelling material, according to circumstances; iron architecture not being dependent on iron only for its ornamentation. Almost every engineering constructional invention may here be indulged in, obedient only to those laws of art requisite for the attainment of relative and harmonious as well as intrinsic use. An intermediate arrangement of skeleton frame-work is here considered necessary, the particular form of which is dependent on the nature and requirements of each work.

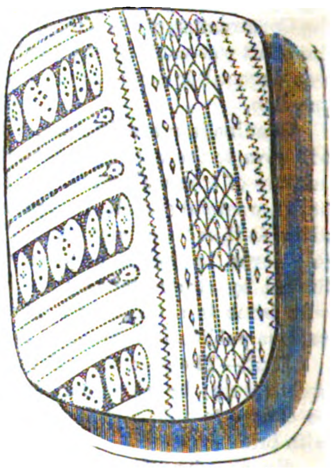


Fig. 94.

The peculiar advantage of the first primary principle is economy in space, which occurs to a proportionately greater extent as the height of the building and its stories are multiplied; an advantage greatly enhanced by the high price demanded for ground in cities. In the case of lofty buildings of brick and stone on confined spots of ground, almost one-third of the whole space is necessarily often occupied by solid walls.

The enormous bulk and weight of the primary materials used in the con-

struction of ancient buildings, and the circumstance of every ordinary brick holding in absorption about three-quarters of a pint of water, with the vast body of dirt, dust, water, and grit inherent in the other materials, must be known to every one. In that great work in the ancient system, the Pantheon, the supporting walls of its celebrated dome are twenty feet thick. In the author's design for an analogous work in iron, but of much larger dimensions, a surrounding space is planned of two walls, twenty-four feet apart, forming canister walls—that is, a wall formed by two hollow walls placed at a distance proportioned to the weight they have to bear, braced together by means of beams, upon which is sustained a dome of infinitely larger span; so that the gain in space would be almost equal to the whole space of the solid walls.

This is likewise shown in the author's design for a domestic palace of nearly 500 houses, where four lofty equal ranges of buildings, forming a hollow square between 400 and 500 feet in length, and of the canister proportion of 50 feet in depth, sustains a quadrangular dome of 300 feet span, on the chain tension net principle of Mr. Bridges Adams, which encloses a court or winter garden, the inner surrounding walk being 1200 feet in length. This roof, which has great architectural capacity, is composed of wrought in connection with cast-iron, paned with thick glass, made water-tight, calked and seamed like the deck of a ship. In this case "the strain" would be distributed, and the weight also would be distributed, on the four walls instead of two. Thus a tension net of iron bars would be formed, possessing the property of a net—viz. that the breaking of a mesh would not involve the tumbling down of the roof: and thus great additional security would be obtained.

The types and features of this palace, which, from repetitions of the same castings, manifests extraordinary economy of construction, were exhibited by the Royal Academy in 1853, amongst other designs of the author.

The protection afforded from heat, cold, and damp, by the admission of a stratum of air between the outer and inner walls, is obvious; and its security from fire is also proved by the fact of the iron-safe, which, when composed of single plates, and exposed to high temperature by the action of fire, becomes red-hot, and causes destruction to the contents; while, at the same heat, perfect safety is secured by the application of a second plate, and the admission of air between the two surfaces.

On the other hand, in illustration of the effect of hollow or double walls in mitigation of cold in interiors, the fact is exemplified in the case of greenhouses, which, though only partially composed of hollow walls of bonded brick, have been found to maintain a temperature so much higher (other contingencies being the same) as to preserve plants in perfect health; while with a solid wall they have been destroyed. This, however, can only be attained in perfection by the application of iron, where the outer wall, inevitably acted upon by heat and cold, and snow and dirt, followed or preceded by rain or damp and dryness, being not partially, but completely separated from the inner wall, the interior remains perfectly free from these injurious effects of sudden changes.

The greatly-increased facilities for the ventilation and lighting of build-

ings, both natural and artificial; for the arrangement of pipes for the conduction of air, gas, smoke, sound, water, and for their removal without injury or destruction; and the almost total abolition of repairs when iron is coated with glass, the colours remaining of almost eternal brilliancy and durability—would take up too much of our space to enter upon.

These vital advantages of the modern material, iron, over those of the ancient, stone and brick, bear a striking analogy to the immaterial truth of the art, architecture, which is founded on their powers and properties. They promise to be unaffected by time, or even use, being not only well-nigh inexhaustible in our own country, but bountifully spread over the habitable globe, and in relation with materials which chemical knowledge and mechanical science are still employed in bringing to perfection.

In the author's designs for a church in iron architecture, constructed of iron, combined with porcelain, glass, slate, &c., without structural use of timber or addition of plaster, the space within the walls affords comfortable sittings for 1250 persons. In a brick and stone church of exactly the same ground and space, and precisely the same plan and arrangement of sittings, accommodation is afforded for 1000 persons. Neither of these have galleries, which is all in favour of the stone building.

In the author's designs for dwellings, warehouses, and other buildings, the saving in space and ground, and many other peculiar qualities, is more strikingly evinced than even in the case of the church; for instance, in two 14-inch or brick-and-a-half-built rooms, each 15 feet square inside and 11 feet high, the number of cubic feet in each room is 4950 feet. These, if built of iron, would, with the exception of where the supports occur, be increased one foot over the walls from floor to ceiling; the double wall—that indispensable necessity in a dwelling—with its air-chamber between, occupying about two inches, where as many feet are demanded for brick and stone. This gives an increase in the iron of 1155 cubic feet; so that, while the brick-and-mortar wall construction affords in vacant space but 4950 cubic feet, in iron or iron and slate-slab occupying the same space, 6105 cubic feet are afforded: allowing between 100 and 200 cubic feet as space occupied by the supports or framing, and for attainment of the effect resulting from light and shade.

On the Application of the First Principle.—The method of supports and panelling is of course adopted as the basis of construction in a metallic system of architecture, from its suitability to the nature and economy of iron and its analogous materials. As a general principle, it has no claim to originality, being sanctioned by experience and frequent use. Though many and various methods of detail may hereafter be adopted, different from those which have hitherto been thought of, and forms and modes devised of such excellence as to carry with them universal acceptance; yet the moderns would not do well to pay the same rigid adherence to the forms, modes, or proportions of an architecture dealing with iron, as was obtained by the Doric and Ionic orders, and the Corinthian column and entablature, of the ancient architecture in stone.

The Second Primary Principle.—Interstitial ornamental form, in substitution of surface-carved, prominent, or basso-relievo form in masonry. Fig. 95 represents an equivalent feature for a boss or flower in the ancient system, to be executed in cast or wrought-iron, or other metal or material, with gilding or other finish, or set or grounded on crystal, or enamelled, as with gems in jewellery.

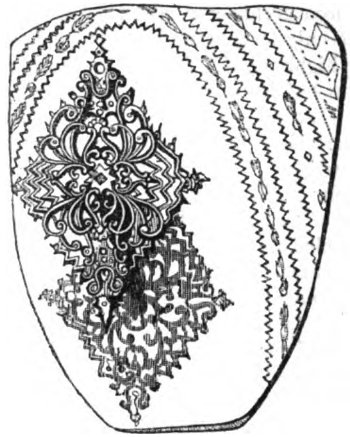


Fig. 95.

The productions of the artistic smith, as of almost every variety of artist, are available, as this must by no means be considered only as an art confined to cast-iron.

This character of decorative form is essential to the development of the peculiar powers which distinguish metal from stone and timber, expressed in its variety of features. It is in advance of and distinct from the surface of the wall, ceiling, and cornices, forming terminations to the pins or screws employed for the security of the iron walls, &c.; such being in strict conformity with that important axiom in architecture, "that the beauty or ornament should issue out of the use or necessity of the construction."

The Advantages.—Capacity for the attainment of distinct and effective beauty in the form itself, by the boldness of its projection, and contrasted material or colour with that of the surface of the wall.

Generic and peculiar beauty, in the production of optical Protean effects, through the projection of its shadows on the delicately-tinted surface in the rear. Nor are other ornamental materials excluded; for, inasmuch as metallic adjuncts have ever been admissible in the ancient system, when properly used; so, in the modern system, stone and marble statuary and basso-relievo and other adjuncts are also admissible, when legitimately and appropriately introduced.

Improved cleanliness, by the passage afforded for wind and water through the interstices of the design, between the ornamental form and the surfaces of the building.

Increased durability of the metallic ornamental form compared with forms in stone and cement; and when, as is often required in architecture, repetition in great numbers of casts from one pattern or mould, greatly decreased cost in production.

In addition to the above peculiar advantages, forms of this description, while they evidence the required freedom of invention requisite in iron architecture, afford opportunities for the introduction of various features, such as

cupolettes, sun-shades for windows, &c., by which peculiar utility is combined with peculiar ornamental effect. Any attempt to establish a system of iron architecture which would exclude this character of form, would be not only to degrade and limit the required use of the material, but would be highly detrimental to the cause of art, as exercising a tyranny over the most legitimate and highest powers of invention of the human mind.

On the Application of the Second Principle.—As in the works of nature, where time, the elements, or other circumstances, have worked upon constructions of the quarry, as in the frequently fantastically relievo form of rocks; so in the modern system, and in the primary materials, there is not one of these essential qualifications but may be exemplified as possessing the charms of a new utility or a new beauty to recommend them; while at the same time that most important consideration, the simplification and economy of building, is effected, and many of its nuisances removed or abated.

In treating of the Second Principle, it is seen that the general abandonment of the particular treatment of the basso-relievo ornamental form, as it is expressed in masonry, is considered inevitable; and in substitution thereof, "Interstitial Ornamental Form" is demanded in metal. For this, several powerful reasons are given in the following extract from the Westminster Review:—"With regard to the merits of 'Interstitial or Transparent Form,' as compared with that which is massive and opaque, from its being carved or cast on the surface of a solid body, it may be remarked, that it would probably be impossible to produce a design for the one which could not, without some slight modifications, be carried out in the other. It is apart from the contingent position and circumstances in which these forms are placed, and the influences which are brought to bear upon them through the agency of light, and its action upon their peculiar combinations, that the excellences of the one in comparison with those of the other can be developed. For example—to compare great things with small—if we take a piece of lace (a fabric in the highest degree susceptible of the beauty of interstitial form), and paste it over a solid body of its own colour, outline, and configuration, it will remain the same. Still beautiful it may be, but illustrative of the effect produced by solid and opaque form, analogous to that exhibited in the surface-carved or relievo ornament of masonic architecture. Again, if the same piece of lace be stretched over a surface of agreeably contrasted colour, the beauty and elaboration of its form will become much more manifest, though still expressive of a solidity coincident with that of a printed or embossed pattern over an opaque substance, rather than of the transparent qualities in which its intrinsic excellence consists. But remove this piece of lace from the substance over which you had stretched it, and place it at a judicious distance in advance of the surface of contrasted colour, the action of light falling variously upon it; and the result will be, not only that the beautiful intricacy of its forms will be prominently exhibited, but a superadded peculiar and highly interesting, and moreover entirely gratuitous, species of beauty and effect becomes produced, through the varied repetition of its forms and combinations, and the ever-varying

modifications of the same in the incorporealities of shadow. Now, though it may be brought within the bounds of possibility to produce interstitial forms of this description in stone or timber, of proportions, it may be said, delicate enough for the purposes of architecture; yet the brittle or fragile properties of these materials compared with the extraordinary strength and tenacity of iron and similar substances, renders the latter the most, if not the only efficient medium, for the realization of the effects to be produced by the systematic use of these forms in architecture."

Moreover, the walls or other parts of buildings, from the surfaces of which features of this character are suspended, being hollow and interstitial, further justifies this character of ornament, since in the ancient and established architectures the ornamental features are correspondent with the wall, each being solid or opaque.

But not only is interstitial, suspended, or transparent form, consistent and harmonious with hollow walls, but the instruments by which it is suspended from the same are of necessity associated with metal constructions; since, from the iron ship of several hundred feet in length, and the iron gasometer of equal circumference, down to the handle of a coal-scoop or candlestick, the pin or rivet presents itself as the expressive medium of connection between the several parts of which metallic constructions are composed.

Another advantage, peculiar to the character and disposition of the ornamental form in question, is its singular power and efficiency for maintaining the beauty of cleanliness.

In the carved or basso-relievo form, especially in exteriors exposed to a humid atmosphere, so fully charged with particles of soot and dirt, and embryo vegetable matter, as our own, it is impossible, without frequently-repeated washing and brushing, to preserve such a state of cleanliness as is requisite to exhibit the lights and shadows of the original work, or to protect the forms in question from the accumulations necessarily engendered within the sunken hollows of carved forms, especially when these are of rich or bold proportions.

In the metallic interstitial form, on the contrary, as applied in accordance with the provisions described, the necessity for cleansing operations of this nature is almost entirely removed: for, independently of the non-absorbent properties of iron, and the absence of the glutinous and slimy surface occasioned by the growth of minute vegetable and animal life, so inseparable from stone; the position in which the various features are placed in relation to the walls (at various angles, according to their office or character), at a clear distance in advance of the surface, is calculated to effect the continual cleansing and washing of their interstices, through the natural action of wind and rain.

The Third Primary Principle, or treatment in close connection with the first primary principle, and in contrast with the second, manifested in medallic low relief, or intaglio form, or repouse work, and generally in obedience to the manipulative requirements and thickness of the plates. This, though involving no invention, constitutes, with the second principle, two distinct characters of form to that of the one principle of relievo form in

masonry, although in the decorations of that system three different characters of relievo, viz. basso, mezzo, and alto-relievo, are employed. Both these distinct principles are demanded for the adequate architectural expression of metallic powers, peculiarities, and requirements in iron architecture.

The Fourth Primary Principle is manifested in the suspension portico, or light-admitting longitudinal covered way, in substitution and equivalent for the columnar portico, colonnade, and arcade in the ancient system; as also in the application of suspension chains and brackets to corresponding towers, turrets, and canister walls; or in supports for sustaining roofs to buildings of such extent as to require, in the masonic arts, the construction of expensive piers and columns.

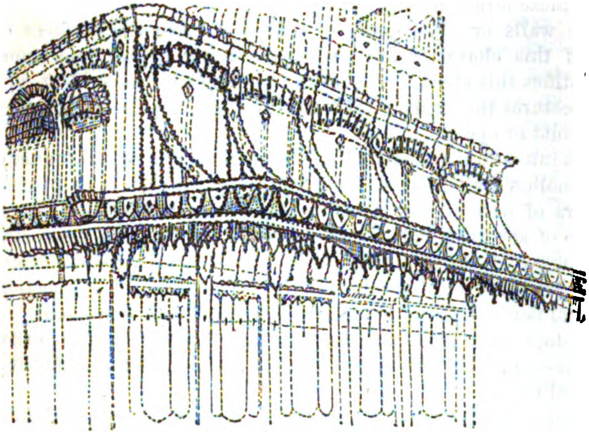


Fig. 96.

Forms and arrangements of this description offer peculiar advantages in application to railway termini and platforms; public entrances and covered ways, perfectly lighted and ventilated, for streets, theatres, and other extensive buildings for purposes of exhibition or assembly; terraces, conservatories, state apartments, &c.

The Advantages specially resulting from the application of the suspension principle are numerous. They afford the shelter of roofs from rain and sun, without the obstruction of light, air, and view, and the saving of the entire space usually occupied by piers and columns; which are generally unfit, frequently highly dangerous, as in some of our railway constructions, and rarely needed in iron architecture, which, in obedience to the hitherto undeveloped powers of the material, admits the utmost liberty of invention, restrained only by obedience to those general laws which alike govern all constructive art. It also offers a facility for carriages to set down and take up passengers entirely under cover, and not beyond the roof of the portico; the saving of all expense in piers and columns; capacity for the attainment of every variety of grace, lightness, and elegance in effect, from the harmonious introduction of colour and resplendence, combined with the due exhibition of those powers and properties which distinguish metal from stone and timber.

On the Application of the Fourth Principle.—It is a rigidly-observed law.

especially throughout the highest productions of nature as in those of art, that out of the primary generic principle issue those which are of a secondary character. However important those secondary ones at times become, they are ever harmonious with that of the parent principle.

The entrance into a different world of construction, whereby the relinquishment of the dead-weight vertical pressure upon the earth, unavoidable in the ancient materials, and so fatal in earthquakes; and the necessarily embracing, amongst others, that distinguishing property of the new and life-like materials, of horizontal thrust, in predominance over that of vertical pressure. In the more ornamental forms, features, and inventions of the second principle, though there is seen to issue the like required abandonment of the heavy stone basso-relievo form, and solid geometric quantity, yet even here the nobleness and (in its own peculiar way) the sublimities of architecture are preserved In the more important assemblage of forms, features, and inventions of this fourth principle, solid geometrical quantity may be fitly said to be described, rather than, as anciently, embodied.

The Fifth Primary Principle consists in the general substitution of curves at junctions to the utmost extent consistent with economy, throughout the primary parts and apertures of buildings, in contradistinction to the angular forms so prevalent in all erections in masonry. The affinities of this general character of form are existent in those orders of natural structure wherein the analogies of metallic structures are found to reside, in which utility the most comprehensive, and beauty the most perfect are manifested; and from the example of which the other distinctive principles of the system are derived.

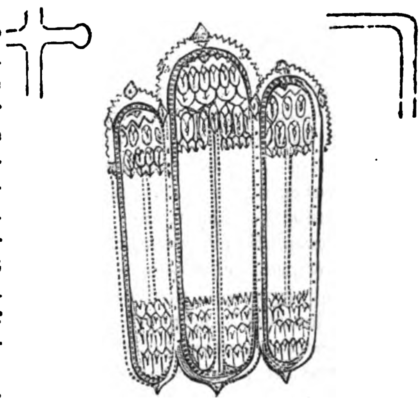


Fig. 97.

The Advantages of this principle are, increased cleanliness from the absence of dirt and moisture, which accumulates in receding angular forms; greater convenience from the absence of the acute projections; increased suitability to the economy and properties of metal, by the avoidance of all tendency to corrode, common to receding angles in constructions; less liability to injurious effects from contraction and expansion; and capacity for increased beauty, from its nearer approximation to the highest order of form in construction.

On the Application of the Fifth Principle.—On the subject of non-angular form, the facts and arguments advanced in the author's various publications all tend to this result, that as in art (to speak abstractedly of lines and forms) the non-angular or curved form is superior in almost every respect to that

which is angular, so this principle must (and in the ablest practical works is) never lost sight of, whether in the constructive or in the decorative manipulation of the material; it is, moreover, advisable to adopt it to the utmost possible extent, where not at variance with the requirements of architecture.

The Sixth Primary Principle consists in the application of a coating of some kind indispensable for iron, such as of glass enamel in colour, patented, and offering a cheap process of almost eternal durability, of paint or gilding; or various other methods, which, though not always necessary in the analogous materials, are ever justified in cases where they are properly applied.

The Application of the Sixth Principle, or appliance of a coating or covering for the iron, embraces in iron architecture a two-fold requirement—namely, the protection of the iron in all cases, in the first place; and in the next place, the attainment of that species of art or beauty which results from the introduction of the varied colour demanded for the satisfactory realization of an art work as an agreeable whole, especially in interiors.

For the first purpose, the patent process of glass enamelling over the iron seems much superior to any other, though various methods suggest themselves. With regard to the second, some observations are contained in the new forms in architecture (sixth principle); but these requirements can only be truly exemplified in designs and in realized works.*

The principle of structure in iron architecture must be analogous with that of wooden structure, dealing as it does with a material adapted for elaboration, in the form of pillars, of framing panels, and tensile beams. It must be composed of frame-work and panelling. Vertical pillars or supports of cast or wrought-iron are connected beneath the surface of the ground by bed or foundation plates, and by horizontal beams at convenient intervals, showing proportional outlines. The main pillars and beams may be subdivided by smaller intersections; or they may, for effect and strength, be grouped alternately, or nearly duplicated. Into these intersections the panels are to be inserted in prepared grooves, the panels being double, and leaving an air-space of greater or less thickness between them, with provision for heating the air, fixed and stationary in cold weather, and current in warm weather, to compensate for cold, by a non-conducting medium retaining the heat in the building, and carry off heat by the cooling process of free air within the double wall. Were the apartments lined with non-conducting materials, the provision for heated air would not be necessary.

The panels may be of cast or wrought-iron, though wrought will be preferable for the lightness which it combines with strength. Occasionally slate or porcelain might be used, especially for interiors; and the surfaces of

* It is more especially under the head of Second Principle that the law has secured to the author the rights of patent. The use of any architectonic features, possessing the essentials of that principle, as also those of the Fourth Principle, are not, therefore, open to promiscuous use. Professional gentlemen and others desirous of extending the *advantages* of the system, may communicate with Mr. Vose Pickett, 58, Jermyn-street, London.

the panels can be cast or embossed, and adorned with devices and ornamental work analogous to the purposes of the building, varying the design to suit the inside and the outside. The same principle of structure will apply to the roofs and the floors; with this difference, that the ceiling plates and flooring plates may be laid on the horizontal surface, instead of being grooved in like the walls. The ceiling plates should be formed by enclosed panels, the apex in the centre of each serving as a ventilating orifice between the ceiling and floor; and the hollow space in the walls and in the floors serving to contain the chimney and warm-air pipes, conveying air to any part of the floor or wall where it may be required.

The plate cases can be of light ornamental structure, and thus in the building itself there need be no combustible material. But it is advisable that the surface of the floors should be of non-conducting materials, and yet a part of the structure. The simplest mode of accomplishing this, is by means of a moveable parqueterie arranged in triangular forms, supported on the extreme points or feet, and standing hollow on the floor below. These can be made of light angle-iron frames boarded with wainscot, of very beautiful patterns, and of great variety, capable of being changed from time to time. By small openings between the edges of the frames a provision may be made for dust to descend, which may be cleared away at intervals by taking up the carpets, or other coverings laid on the parquet flooring.

It may not be out of place here to describe an iron-framed and slate-slab house which was built by Mr. George, and satisfactorily tested. The house was about 24 feet in length, by 13 feet in width; of two floors, with two rooms on the lower floor and two on the upper; the whole quantity of wrought-iron (there was no cast used) was between 1½ and 2 tons; the quantity of slate-slabs about 27 tons—walls, floors, ceilings, roofs, stairs, chimneys, doors, &c., being all of this material: the whole structure, with the exception of the glass for the windows, being, in this instance, limited to these two materials. The weight of a brick-and-mortar and tiled house of like dimensions would be about 120 tons, or four times that of the slate house. If the house had been panelled with iron, it would have been of considerable less weight. The space occupied by the double walls, with the air-chamber, was 2½ inches. The outside walls were composed of 1-inch thick slabs, upwards of 8 feet high, and 3 feet 9 inches wide; the inside wall slabs were about ⅝ths in thickness: so that this small structure of wrought-iron framings, panelled in with slate-slab, almost rivalled a construction of iron only. It was put together on the dove-tail principle, without the use of pins or screws; and when prepared, a few days would, and did, suffice for its erection. The inventor, Mr. Joseph George, did not, in this instance, perfect it; yet it is valuable as leading the way, and showing one method, of the smallest and most economical possible use of the great staple material of the new system.

Here was a construction, fire-proof, undecaying, formed like a box, bound together at the foundation as well as roof, and of such stability, that if exposed to the most tremendous earthquake, even if thrown upon its

beam-ends, it would have every prospect of remaining uninjured—a perfect contrast to brick and stone erections, which exist by means of vertical pressure upon the earth, while those of iron exist by horizontal thrust. This construction, if a humble, was an honest building. The builder says, with all its advantages, he can produce it cheaper than brick. The history of this house, unfinished, would furnish an eloquent lesson for the public to think upon as well as act for themselves, if we had space to dwell upon it.

About 1850, a granary was erected for the use of the Queen's stud, which may be seen at Cumberland Lodge, in Windsor Park, of wrought-iron and slate-slab. It was elevated upon brick to the height of the floor of a waggon, which was not a necessary part of the construction; while the imperfect inner wall was of wood. But this construction, when perfected, is capable of application to works of magnificence, as the writer has applied it in his designs for a church. It must be stated, that in the granary the extremely small quantity of iron used was such, that the builder had to rely for rigidity and stiffness, to a very considerable extent, upon the panelling. This compelled him to fill in his panelling simultaneously with the erection of the framing—a manner of construction which, though capable of improvement, has certainly not the advantage of that judicious use of cast with wrought-iron, exemplified in the previous erection of the skeleton or framing, as the appropriate law of a truly architectural work.

CHAPTER XXV.

IRON-WORKING IN ITS APPLICATION FOR USE AND ORNAMENT.

General Remarks.—The preceding treatises have hitherto dealt more particularly with the manufacture of iron, and its application to the construction of those great works which have earned for our country a reputation bounded only by the limits of the world itself. England is emphatically the emporium of iron manufacture; and in every land are the products of her manufactories, and the labours of her artizans in that metal, to be found. It has been remarked, that the extent of the production of iron, in connection with the skill with which it is worked, is a true index to the civilization and intelligence of a country. If you want to arrive at this, learn, says Chevalier, if much iron is consumed; look at its tools, utensils, and machinery; examine what figure iron makes among them; and if these are numerous, solid, and well made,—if iron, whether cast or forged, or converted into steel, enters largely into their construction,—if the workmen who use these do so with facility, if they keep them in good order,—then, if such is the case, you may with closed eyes declare that the nation the artizans of which can do so is advanced, very far advanced, in industry. If, on the contrary, the consumption of iron is limited,—if the iron tools are badly made, and if in the machinery or apparatus iron is but sparingly used, and then in connection with bad workmanship and inferior finish—declare that that nation is behind the age, and must be classed in an inferior rank. By patience and perseverance a few branches of industry ministering to luxury may achieve perfection; but in general its position will be only secondary and its production limited, the tools inferior, the machinery bad and defective: deprived of such comforts as flow from cheap production, consequent upon superior tools and the cheap raw material of which these are made, the population will be comparatively miserable. Great and skilful as many comparatively uncivilized nations are in the manipulation of gold, silver, and precious stones, it is the subject of remark how very crudely made and inferior are the examples of iron-working, where such are to be found fabricated by the workmen of the country; objects resplendent with gold, show, where portions of iron are introduced, that these are crudely made, rough on the surface, imperfectly welded, unequal in thickness, and covered with hammer marks. These defects are traceable to their having but little iron, and, as a consequence, being comparatively ignorant of the art of working it. The Age of Iron, of which poets have written so disparingly, is not, then, after all, the hard, unfeeling, cold material age which they have visioned forth; but is one of increased comfort and happiness to the thousands who live, move, and work under its benign auspices. England without her iron would only

occupy an inferior position among the nations. Take from her her railroads, which spread like net-work over the length and breadth of the land; her locomotives which traverse them; her enormous iron tubes which span the estuaries of the Menai and the Conway; her iron steamers, which bridge the seas; her stationary steam-engines, which endow with vitality millions of spindles in Lancashire alone, and give life and motion to thousands of ingenious machines in Warwickshire and Staffordshire; her Crystal Palace, which glistens in the morning sun on the heights of Sydenham: without her iron, untilled would remain much of the land on the surface of the globe; rank vegetation would cover, choke up, and place a limit to the fertility for useful purposes of the fairest regions of the earth's surface: the ore would sleep in the darkness of the mine—the wild beasts of the forest roam over the prairie and prowl in the jungle, contesting their empire with that of man himself; millions of doors would remain unfastened; thousands of appliances which are used, and are now essential almost to the very existence of mankind, would be denied them. In the production of these, England, thanks to the abundance of her iron, has so succeeded in acquiring the means of cheaply making them, as to secure a market for her products in that material in every quarter of the world. With these remarks, we proceed to direct attention to the manipulation as employed in the making, manufacture, and practical application of iron to the smaller articles for use and ornament formed from that invaluable metal.

Manipulation.—Iron may be worked in two different ways; namely, it may be run, when melted into a fluid state, into spaces formed in sand by the use of patterns or moulds, which leave their impress in it; and in its malleable state it may be hammered or forged. In either case a considerable amount of manipulative skill is required; and just in proportion to the practical knowledge and skill of the workman employed, is the excellence of the workmanship produced.

At page 203 will be found a general description of the process of founding and moulding in the various branches of open, green, and dry sand, as also the formation of loam moulds; the methods therein described give an excellent idea of the principles of moulding employed in the formation of the larger examples of iron castings.

The casting and moulding of smaller works is performed in identically the same manner, the only difference being the adoption of a finer sand, and in greater attention being paid to the "facing." When the object desired is of an ornamental kind, its surface is covered with minute details, the result of the united labour of designer, modeller, and chaser. In Chapter X. the works, the moulding of which are therein described, are large, and require solidity rather than smoothness of skin as a first requisite: for such the patterns are formed of wood; but for smaller and more ornamental castings, the models or patterns are usually made of block tin, any alloy of tin and lead, or, what is better still, of brass—the advantages possessed by the latter material over the first being its hardness and its fitness for preserving the "matting" or "chasing" when such is introduced. It also assists in

retaining the sharpness of the edges of the ornament under the abrasion arising from its frequent removal from the sand; and in patterns of a slender and delicate kind, it is less liable to the distortion which would follow any accidental blow which it might receive while undergoing the process of moulding. Brass is also superior to iron, as being less liable to sweating, less liable to encourage the damp arising from the sand in the formation of the mould, and which induces the adhesion of the sand to the model—a contingency which it is well to avoid as much as possible. Every iron-founder, however, has in his pattern-room a considerable amount of value in iron patterns, which if made of brass would form a very considerable amount of sunk capital; this consideration, doubtless, determines in many instances the adoption of iron. Another kind of pattern is formed of wood, with the ornamental portions of metal; these are stuck on the wood foundation with spikes or screws. It may be here remarked that ornamental patterns of metal for grate or stove fronts, fenders, and railings of various kinds, are not usually matted, but require to be made smooth by a scraper. By whatever means, or out of whatever material, the patterns or models are made, their end and intention are the same,—viz. to form an impression in the sand, a matrix or cavity into which the melted metal is to run.

In considering the casting in copper and its alloys, the various processes pursued in the construction and preparation of the moulds or patterns of an ornamental kind will be explained at length; for the present we will presume that the pattern is made and placed in the hands of the moulder, whose part it is to take a perfect copy from it. There is little difficulty in accomplishing this if the subject is of a simple kind, such as an ornamental panel in low relief, with every portion of the ornament tapering outwards, and presenting no portions which are either quite perpendicular or overhanging: perpendicularity increases the difficulty of removal, and overhanging portions tear the sand away. Where the subject is in alto, or full relief, as in figures, animals, foliage, or flowers, there is great difficulty, and a very considerable amount of skilful manipulation required; in truth, it can only be accomplished by increasing the number of pieces of sand, or building up, bit by bit, the mould by means of what is technically called "false cores:" what these are will be best understood by referring to the cut of the pulley moulds at page 206. It will there be seen that the cavity or groove in which the cord is intended to work, could not be taken from the sand in the mould were it simply imbedded in the sand of a two-part casting box, and were the pattern in one piece, because it could not be removed; or in the removal that portion of the sand which fills the groove in the mould would be torn away in attempting its release, and instead of a groove we should have a solid mass of metal: this is obviated by the construction of the pattern, which is in two parts, separating in the centre, and fitting together by means of a pin. The sand which forms the mould is in three portions or masses, two of which form the parts corresponding to the sides of the pulley, and the third the groove. It is by the multiplication of separate portions of sand or "false cores," corresponding to that which forms the groove of the pulley, that the

moulding of complex castings of an ornamental kind is effected. If, for example, we desire to produce a mould from a figure in full relief, where the drapery represented is in deep folds, and the arms stand out from the body, it must be evident that at the sides the sand would be torn away by the folds of the drapery; and the same result would follow with that portion of the sand which filled up the space between the arms and the body: this is obviated by the pattern being so constructed that it can easily and readily be put together or taken to pieces when in the sand. The drapery, again, presents an obstruction; but here the "false core" system comes into play, and piece after piece of sand is added, until the whole of the pattern or mould is covered. The consistency to which the sand is brought, and its cohesive properties, permit of the separation or lifting away of these "false cores," and the removal of the pattern; when these are again replaced in their proper situations, and the mould closed. The careful joining of these "cores" is a matter of very great importance, in order to secure good work with as little roughness at the junctions of the several separate pieces of sand as possible. The steadiness of these cores when laid in is also a matter of moment: did one of these project too much into the matrix, a hollow or imperfection would be shown in the casting; on the contrary, were one of these to move accidently too far back, when the box is prominently closed, a rotundity would be the result: in either case, there would be an imperfection in the casting.

In ornamental examples of iron casting, it is much more necessary that these should be cast more together or complete than in either brass or bronze casting. In the latter, separate pieces may be attached by means of hard solder; but the iron-founder cannot apply hard solder: he can only have recourse to pins or screws to form his attachments where he casts his work in pieces. If we take, for example, the model of a horse or stag standing upon its four legs; in either case, the trunk of the animal could be cast separately, the legs also separately, and these might be screwed into their proper places. For purposes of sale, no doubt the above method is by far the most economical of time; but viewed as a *bona-fide* exemplification of the moulder's art—and this is what is being aimed at—the attachment of the extremities by means of screws takes away from, and reduces very considerably, the merit of the work. In the admirable castings of an ornamental kind produced by the Colebrookdale Company, and of the smaller class of work, as many as 150 cores are used; and the time consumed in the preparation of the mould extends to eight or ten days in each case. One of these cores, introduced in a careless manner out of its proper position, would certainly render valueless all the time and labour expended. To produce good castings, the principal requisites are these:—A good and well-made pattern; if ornamental, or where there are parts in full relief, that these parts should be so made that they may be alike easily removed and replaced, and at the present time show no marks at their junctions; that where prints are introduced, in order to rest cores upon—not false but *real* cores—such as serve to lighten the casting, as in the body of a horse, which may thus be cast hollow,

such cores require to be so much smaller in every direction, as to produce the thickness of the metal desired, on its being run into the space left between the core and the outer impression produced by the pattern.

It is necessary to observe that these prints are so placed as to allow a secure rest for the core laid in them; the sand should be of a fine tenacious quality, which, when pressed into the moulding-box, will cohere together, and at the same time allow the damp, which is generated by the heat of the melted metal poured into the moulds, to escape. The workman must be possessed of patience and perseverance, of much mechanical ingenuity, so as to be able to detect the causes of failure when the pattern does not leave the sand in a smooth manner. Any tearing away of the edges of the mould, the skilful moulder will at once perceive has arisen either from his negligence in sinking the model below its proper line, or from an error on the part of the pattern-maker. This error, once detected and corrected, should not occur again, and be attributed to the modeller.

The method more commonly in use in iron castings, where a smooth surface is desired, is to "face" the mould, as it is technically called by the workman; that is to say, cover the pattern with a layer of fine sand, known as "facing sand;" the remainder of the box being filled up with a sand of a coarse and freer consistency, which facilitates the escape of air. In addition to this, it is not unusual to remove the pattern or model, and dust the impression with powdered charcoal—a charcoal formed from burnt wood, and very finely ground; to re-introduce the pattern, and apply additional pressure; and after finally removing the pattern, increased smoothness of surface and fineness of texture will be found to be the result of this practice. In our own experience, we have seen many excellent and valuable castings spoiled, and much valuable time wasted, by neglecting to provide free exit for the air and moisture. Another defect in castings not unfrequently arises from what is called the "washing" of the sand; *i.e.* the sand not being sufficiently tenacious or adhesive, the sharp edges of the impression are carried away or defaced by the action of the fluid metal in its progress. The consequence is, that in addition to a want of sharpness in the cast, there is a roughness arising from the minute particles of sand so washed pitting the surface. These defects would be at once recognized by a competent judge, and the casting in which they were evident would be at once rejected. The old method of casting such articles as stove-fronts and portions of fenders, with a two-part box or moulding-flask—namely, filling up the first half, laying on it the pattern of such articles as have already been named, and after the application of the parting powder, making up the second half of the box or flask—is a process which had long been practised without improvement, until very recently, when Mr. Jobson, of Dudley, invented and patented a method by which the moulding of simple ornamental castings was reduced to an operation of the utmost simplicity; greater accuracy being also secured, and the perfection of the mould very much increased, the castings produced therefrom having, at the same time, less "fin" or roughness at the edges, and more uniformity in thickness; while the chances of bad castings are very much diminished. The

formation of the mould by this process may be confided to a very ordinary workman, who has simply to fill in and beat the sand into the half-boxes placed on the surface-blocks—the one corresponding to the front, the other to the back of the casting. No care is required to secure the safe removal of the pattern, as it is stationary, and the two parts of the box have simply to be placed together when completed. As the improvement is an important one, we give the process *in extenso.*

In the ordinary plan of moulding with "odd-side boxes," the pattern from which the casting is to be made is imbedded partly in the sand of the top box, or in an odd-side board prepared for the purpose; the bottom box is then placed upon it, and rammed full of sand, imbedding the rest of the pattern; the boxes are then turned over, and the "top box" or "odd-side" lifted off, leaving the pattern in the sand in the bottom box; "parting sand" is then applied, and another top box rammed upon it, the pattern still remaining between; the boxes are then separated, the odd-side is again put on, the bottom box turned over, and the pattern left upon the odd-side. After the impression of the pattern in the sand of the two boxes has been completed, and any damage done in removing the pattern repaired, the top box is again placed upon the bottom one in its original position, and the preparation for casting is complete.

When the pattern is long, and very thin and intricate (as in the case of an ornamental fender front), where the general surface is also curved or "winding," as in Fig. 98, the difficulty of picking out the pattern from the mould is so great as to require the most skilful workman; and the length of time required for repairing the injuries of the mould is such that eight sets of fender castings per day is the general limit to the number that can be moulded by a man and boy. But however difficult a pattern may be to mould in the ordinary way, if it is arranged to "draw" properly from the mould by the new process, the labour is very little greater than with an easy pattern; and the saving of time is so great, that as many as thirty per day are moulded by a man and boy, being four times the number that the best moulders can produce by the ordinary plan.

When the pattern is long and slender, it is liable to be broken by the frequent handling to which it is subjected in the ordinary process of moulding, and the expense and delay caused by such breakage is of serious consequence in light ornamental work, where the patterns are often very expensive; by the new plan, however, this is entirely avoided, as the pattern is never handled at all, except in the original process of moulding to form the ramming-blocks. When the face of the casting is required to be particularly well finished (as in the case of ornamental work), a brass or other metal pattern is prepared and dressed up to the degree that may be desired in the castings, and any chasing or additional ornament put upon it; then, after forming the ramming-block for the bottom box by a plaster cast from the pattern in the manner hereafter to be described, the pattern itself is made to form the permanent face of the ramming-block for the top box (as in Fig. 98), by leaving it in the mould when the plaster is poured in, so that the

plaster forms merely the parting face and a solid back to the pattern. In this case the iron pattern is secured to the cross-bars of the box by several small bolts, screwed up to plates at the back of it; so that when the plaster is poured in, filling up the whole vacant space of the box, and setting solid around these bolts and over the nuts, the iron pattern becomes so firmly secured in the box that no ramming or moving to which it is afterwards subjected has any chance of loosening it.

Fig. 98.

The process will be better understood by referring to the annexed woodcuts, wherein Fig. 98 shows the pattern attached to the surface of the ramming-block or bed; from this is made the ornamental face of the casting. Fig. 99 shows the ramming-block for the back part of the casting; Fig. 100, the two parts of the mould closed together; and Fig. 101, the section of the mould-box, showing the arrangement by which the two parts of the box are held steadily together, and by which they are made to register correctly.

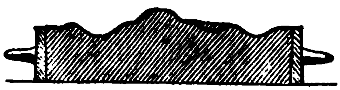


Fig. 99.

In this plan the mould for the face of every casting is formed from the original metal pattern, and the pattern itself is firmly and permanently secured in the plaster bed; so that, however thin and delicate it may be, there is no risk of injury to the pattern in moulding any number of castings; as many as 3000 have been cast without injury to even slender ornamental patterns by this process. In forming the ramming-blocks, common plaster of Paris is most generally employed, as being the most convenient and economical material, and is found to be sufficiently durable for general work: as many as 4000 castings have been moulded from one pair of plaster-blocks.

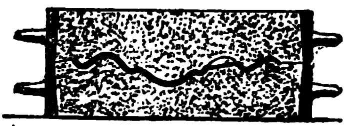


Fig. 100.

When a greater number of castings are required to be moulded from one pattern, or when the size or nature of the mould renders a harder face advisable, a metal face is employed for the ramming-block of the bottom box, or for the parting surface of one or both blocks. This is formed simply by running into the mould, when prepared for the plaster, a small portion of metal, consisting of zinc hardened with about a fifteenth part of tin, sufficient metal being used to form a strong plate for the surface of the ramming-block, and the rest of the space at the back filled with plaster as usual. In practice it is more convenient generally to reverse the mode of running the metal face, by first ramming the box full of sand, when prepared for the plaster; then lifting it off, paring off the surface of the

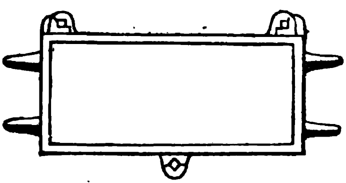


Fig. 101.

sand wherever the metal is wanted, to the thickness which it is desired the metal should be; the box is then closed, and the metal run in. The sand is now removed from behind the metal, and its place run full of plaster of Paris—whereby a solid back is made; snags or dove-tail blocks at the back of the metal face secure its attachment to the plaster. Various modifications of this plan may be adopted; but in every case the entire face of the two ramming blocks form a perfect counterpart of the intended casting, half being represented upon each, surrounded by parting faces which exactly fit each other, because the one has been moulded from the other. The plaster running-blocks are varnished when dried, to preserve them from damp; in moulding from them, the faces of the blocks are dusted with powdered resin, to prevent adhesion of the sand. It should be remarked that the grand advantage offered by this system of moulding is, that little additional work is required over the process for the first moulding, as practised by the ordinary method. In addition to the above advantages, a very clever and simple provision is made for insuring steadiness in the two parts of the mould when closed. Instead of four round pins fitting into corresponding holes, drilled in lugs attached to the boxes, as is commonly done; in the new boxes, vertical studs or square pins are cast on each bottom box, which fit or jam against corresponding projections on the edge of the top box, as shown in Fig. 98. The only fitting necessary in making the new boxes is to file the touching angles of the pins so as to fit one standard top box, and the projections on the top boxes to be fitted to a corresponding or standard bottom box.

An additional advantage secured by this plan of moulding is, that while by the old process only one side of the pattern is available, while the other is in use; by the process just described, the moulding of both sides of a pattern may be carried on simultaneously. The advantages which the new process gives over the older method of moulding, where numbers of articles are required, is so obvious as scarcely to require a thought; and the belief that sufficient publicity has not been given to it, has induced us to notice it at this length, conceiving that our space could not be more profitably employed.

Berlin Iron Castings.—But probably the most wonderful and minute examples of castings in iron will be found among those imported from Berlin. Here we may remark how enormously, by the value of labour, that of the raw material is increased. It has been shown by Babbage, in his invaluable work, "The Economy of Manufactures," that the pendulum spring of a watch, which governs the vibrations of the balance, costs, at the retail price, twopence, and weighs just 15-100ths of a grain; whilst the retail price of a pound of the best iron costs only twopence. Out of that weight of iron, fifty thousand of such springs are made. In like manner, the skill of the Berlin iron-caster so increases the value of the raw material, that the gray iron out of which these small articles of bijoutry and ornament, consisting of buckles, neckchains, earrings, buttons, seals, &c., are cast, realizes in the larger examples one thousand one hundred times, and in the smaller or more delicate objects ten thousand times the original cost of the material. The

great beauty and exquisite detail which is observable in some of these castings is due alike to the extreme purity and fluidity of the metal out of which they are cast, and skilful moulding.

The French chemist, Dumas, has ascertained the presence of phosphorus and arsenic in the iron from which they are cast. The former material, it is well known, is favourable to fluidity when incorporated with the melted iron; it also imparts to the iron with which it is mixed a considerable degree of hardness. These castings are never made from the first, but from the second melting of the metal; the great point aimed at being to get rid of the carbonaceous particles which always render the surface of iron-castings more or less rough. The moulds for these castings, according to the same authority, are formed of clay or argillaceous sand.

From Ehrenberg, who read a learned paper upon the subject before the Academy of Sciences at Berlin, we gather some additional particulars worthy of notice. He states, that the bog-iron ore of which the Berlin iron-castings are made, had its origin in once living and breathing things, which fed on plants and had the power of motion—an animalcule which bids defiance to the action of one of the strongest acids used in the manufactory, viz. muriatic acid, retaining its vitality when immersed therein. The moulds in which these ornaments are cast are also made from the organic remains of animals, their shells forming Tripoli, or ordinary polishing powder. Many of these castings are as thin as sheet steel; thereby demonstrating alike the extremely fluid state to which the metal must have been reduced, the fitness of the sand to take the impress of the delicate mould or pattern, and the great skill of the artizan who prepared the mould. Where chains are produced in Berlin castings, the central rosette, which forms the ornamental portion of the link, is the only part really cast, the loops forming the connection being of wire bent to form and laid into the prints provided for them in the mould; in that state the metal to form the rosette is run in, fills the impression of it, and surrounds the prints or ends of the iron hoops, thus forming the link—two of which being laid at a proportionable distance in the mould, and a connecting link being moulded with a core in it between these, on the metal being poured in, the space not occupied by the wire is filled with metal. After cooling, and the core being destroyed, the iron hoops attached to the rosette will be found encircled with the connecting link, perfectly united together, and free to move.

Holtzapffel in his work relates an example of chain casting executed by a German workman at the Hayle Foundry in Cornwall, in which every portion of the links was cast: its length was nearly five feet, it was made up of 180 links, and weighed a little more than 1¼ oz. In it the links were cast separately; a solid model of the chain was then made a few inches in length, with core-prints corresponding to the apertures of the connecting links; the links already cast were laid in their appropriate places, after being smoked, in order to prevent their adhesion or fusion when the melted metal which was to form the connecting links was run in, "gats" or passages being made to the prints of the connecting links by which to introduce the melted

metal; the box being then closed, the metal was poured in. On opening the box, the chain is completely formed, reticulated freely, and is, at the same time, firmly united together: a large and small link of this chain weighed about eight grains! To understand the process of the formation of Berlin iron chain work, reference may be made to Fig. 102, which shows a link complete; the ornamental centre being cast-iron, the two loops or circles being formed of wire. Fig. 103 shows the section of a link, by which it will be seen that the wire loops are imbedded in the iron which forms the centre.

Fig. 102.

Fig. 103.

This is effected by the pattern of the ornament having a print of the two loops in addition to the centre; the wire loops BB have their ends sufficiently long to project into the space to be filled with iron to form the ornament; the metal being run in, the wire hoops are securely held. The means by which these are connected together and the chain formed, are shown in Fig. 104, wherein is represented two ornamental links BB, with the pattern of the connecting link indicated by the flat horizontal band, and shown in section at D. CC is the core print, by means of which the connecting link is cast hollow; when laid in the position represented, and the core CC placed, runners for the introduction of the metal are made, the box closed, and the metal is run in. If the operation has been carefully conducted, a perfect union of two links will be the result: in addition to being connected together, the three links will move freely within each other. It is somewhat amusing to contrast these minute castings in iron with the enormous casting which formed the cylinder of the hydraulic press, twenty-two tons in weight, which assisted in heaving up into mid-air the tube which the genius of Fairbairn designed, and which now bridges the Menai Straits.

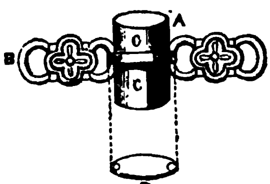


Fig. 104.

The history of this ingenious manufacture is identified with the struggles of the people by whom they are chiefly produced, to rescue their country from the iron grasp of Napoleon. The jewels and trinkets of gold in the possession of the nobility were sent to the national treasury, and melted down to pay an army for its defence: and in exchange, rings and other tasteful ornaments were supplied, bearing the inscription, "I gave gold for iron." Many of these objects are still preserved as precious heir-looms in families of distinction. The impetus given to their manufacture has not, however, been without its evil effects. Very inferior articles are now produced, and few examples are to be met with equal to the productions of an earlier period: this is attributable to the originals having been copied by inferior manufacturers. While some are inclined to attribute the great excellence of earlier examples of Berlin castings to the quality of the iron, others ascribe it to the sand or clay in which the moulding operation is performed, and others to the skill of the moulder. It is more than probable that the three essentials named require to be conjoined in order to produce a successful

result. The reasons will be found in the fluidity and purity of the iron; the fitness of the argillaceous sand or loam to receive the minute impression of the ornamental portions of the model, combining with that quality a sufficiently refractory character to stand the heat of the melted iron; at the same time the moulders must be workmen of rare skill and patience. In these three requisites, we think, lies the true secret of the great superiority of the iron castings known by repute as those of Berlin.

Malleable Iron Castings.—The great cost attendant upon the formation of smaller objects in iron, where numbers are required, naturally directed the attention of the manufacturer engaged in their production to some means by which the iron could be more readily brought into shape, than by forging from the bar or rod by the blacksmith. He was aware that for the purpose, casting was by far the readiest method by which this could be effected; but cast-iron, he knew from experience, was brittle and unfit for the purpose: but could he impart to cast-iron the property of malleability—could he succeed in rendering it soft, pliable, and partially ductile, his end would be gained. Scientific men told him that the brittleness was owing to the presence of carbon; to get rid of this was the desideratum; could he do so, the cast iron article would be reduced nearly to the condition of that formed from the wrought material—destitute of fibre, it is true, because, not being subjected to the operation of rolling or the tilt hammer, the fibrous arrangement of the particles had not been evolved. Having arrived at this knowledge of his wants, the idea of subjecting cast-iron to the annealing proces, in immediate contact with a substance which would operate in abstracting the carbon, suggested itself. It is remarkable that the iron selected for the purpose of, and best fitted for, being rendered malleable, is that which is hardest, most fragile, and brittle. The rich Cumberland iron procured from the hæmatite or nodular ore is that preferred. The castings are made in sand in the way usually practised; and in order to render the metal malleable, it is enclosed in iron cylinders with ground hæmatite ore, pounded iron-stone, smithy scales, or some other substance which absorbs carbon, the cylinders containing the castings being stopped up or covered with an iron disc or cover, carefully luted with clay, in order to prevent the escape of the surrounding substance; the cylinders are then placed with their contents in suitably built furnaces or muffles, and subjected to the action of a red heat, till, in the judgment of the annealer, the desired result is attained, which may occupy some days. The cylinders, with their contents, are then allowed to cool within the furnaces; and when cool, they are withdrawn. The thinner castings will be found to be completely softened throughout, and may readily be bent into any curve; others which are thicker, on being broken, will be found to be annealed to a considerable depth, and even the interior portion will be found to have participated slightly in the annealing process; at all events, the nature of the brittle material out of which they were cast will be found to have undergone a change. Taking advantage of this process, numbers of small articles which had been previously produced from wrought-iron, and which required a considerable amount of labour on the part of the black-

smith, are now cast. Among these may be enumerated the butt-plates, guards, and other portions of metal used in the gun trade; snuffers, &c.

In no manufacture has the process been more largely taken advantage of than in that of saddlers' ironmongery. Stirrups, bits, the fanciful spurs imported to South America, buckles, &c., are made therefrom. Very recently, an importation of German tools startled the manufacturers of this country, by the extremely low price at which they were offered for sale. On trial, however, it was found that the pliers, on pressure being applied, gaped at the mouth—they refused to cut, hold, or grip; the chisels became blunted; the hand-vices refused to pinch or hold. On examination, they were found to have been formed of malleable cast-iron, hardened after undergoing a rough finish by grinding or smoothing; not by means of the tedious process of case-hardening—that is, by being enclosed in a close iron case filled with charred animal substances, such as leather, horns, hoofs, or burnt bone-dust, and subjected for some hours to a red-heat, and when in this heated state, plunged into oil or water,—but simply by heating them over an open charcoal-fire, and, when at a dull red-heat, sprinkling on or rubbing over them the substance known as prussiate of potash, thereafter cooling them in water. The superficial character of this hardening being only skin-deep, allowed the interior of the metal to retain its malleable properties; but whenever pressure or abrasion was applied, the nature of the material of which these tools were formed was disclosed. For many purposes the articles formed of iron, cast and annealed, *i.e.* rendered malleable, are very useful; and for all purposes where ornament only is aimed at, it may be questioned whether it might not be very much more extensively applied, more particularly in the formation of light railings for civil and ecclesiastical purposes, and for ornamental iron-work generally, where a considerable amount of uniformity in ornament is desired. The character of wrought-iron might be given to these; they could be cast very light, rendered malleable, and all the liability to fracture common to ordinary cast-iron would be avoided. It occurs to us that the application of iron thus treated has not as yet nearly realized the importance to which it is entitled. Hitherto the articles made out of malleable iron have been small and unimportant; this, in all probability, arises from the cost consequent upon annealing; the material, fuel, and time consumed, all entering into the calculation of the malleable-iron caster in his charges.

More particularly would the application of this material be advantageous in the formation of iron-work of a mediæval character. Crocket, finial, and fleur-de-lis could then be cast flat; the soft and pliable nature of the material would admit of their leaves being bent and twisted with the utmost facility; time would be saved, and the general feature and quaintness of the style preserved. Doubtless, however, science has in her stores laid up for the patient inquirer, some ready and economical means by which the process may be cheapened; and then doubtless its application will become more general.

In concluding our remarks on the manipulation of iron by the casting process, we need scarcely remind our readers of the very successful examples

which have been brought before the public in the recent Exhibitions of Industry. The gates of the Colebrookdale Company, which now form one of the entrances to Hyde Park; the rustic dome, the Eagle-slayer, the fountain, the numerous statuettes, examples of metallic furniture, stoves, and grates, contributed by the above-named company, which formed so prominent a feature in the Exhibition of 1851; Cottam and Hallam's gates, formed of a union of cast and wrought-iron, and partaking, as a whole, of the style of work known as wrought; the magnificent castings sent by the Sheffield and Derby iron-founders; the Carron Company in Scotland; with many other examples sent by the continental iron-founders,—all alike demonstrated that the art of casting in iron is well understood. But its fitness for public decorative purposes has hitherto been but sparingly tested. Coupled with the improvements for the protection of iron from oxidation, which have now, by the discoveries of science, been placed in our hands, there seems to be every reason for recommending its being employed much more extensively in statuary castings, and in the production of street fountains, than has hitherto been the case. The cost of the material is trifling in comparison with that of marble or bronze: to the former it is superior in its strength; to the latter it is quite equal, if well protected. The production of an iron statue or fountain is not likely to diminish, but rather to increase the skill of the moulder, in the careful preparation of the mould: for while in bronze-casting the nature of the material admits of considerable liberty being taken in repairing it; in iron, on the contrary, should the cast be defective, repairs, if they can be effected at all after a defective cast has been made, are always difficult. Hence the production of artistic objects in iron, from the care and skill required in the formation of the moulds, would educate the artizan, and increase his manipulative skill; while it would at the same time, from the low cost of material, greatly aid in the cultivation of the public taste, if more generally applied. The fine skin visible on the best English iron castings is a proof of the perfection at which we have arrived in the casting of iron. The fluidity of the metal, when in a melted state, as compared with bronze when in the same condition, is also another recommendation in favour of iron.

CHAPTER XXVI.

THE MANIPULATION AND CONSTRUCTION OF WORKS IN IRON CHIEFLY OF AN ORNAMENTAL KIND.

We have hitherto dealt with iron, more particularly, as brought into shape by the formative process of casting. This method, there is every reason to believe, has acquired a greater amount of development recently, in consequence of the demand for machinery, whether for stationary or locomotive engines, or machines for manufacturing purposes. In the working of wrought-iron, however, if we except examples of a very large size, such as Mr. Clay has operated upon and described, it is no injustice to say, that those who preceded us were our equals, if not superiors. In the great we have overlooked the small; in the application of wrought-iron for utility, we have underrated its importance and value for decorative purposes, which is somewhat surprising, considering the importance its great strength in connection with its lightness and fitness entitles it to. The capabilities of iron are numerous: while it is light, it is also strong; it is dense, yet ductile, and, at the same time, easily worked in its heated or cold state. Its value for purposes of ornament appears to have been better understood in many other countries than in our own; and in our own, when the material was not so plentiful as now, great artists and skilful artizans thought it not beneath them to expend upon iron an amount of labour and "cunning" which at the present day it is almost a rarity to see expended on works executed in the precious metals. Doubtless the skill of the hammerman decreased with the more general adoption of casting iron into form. It should, however, be borne in mind that iron, when cast, is necessarily fragile; to secure strength, increase of material is required; and to produce castings, patterns are required to be modelled from. The cost of these, unless distributed over a great number of castings of a similar kind, involves a considerable expenditure of time and capital; and after all, when the cast is made, we lack the crisp, sharp edges, and deep overlays of that which results from the use of wrought-iron worked by the hand of the intelligent blacksmith. In connection with this, it is to be borne in mind that the constant repetition of the same pattern or ornament becomes painful to the eye; and is, in the end, subversive of all desire for new and elegant forms —a desire which, in so peculiar a manner, encourages alike original design and the skill of the artizan.

It was remarked by the late A. W. Pugin, to whom we are indebted for the revival of many of the all but lost methods of working in metals, "that in ancient iron-work we may discern a peculiar and distinctive manner of execution suited to the material, and quite distinct from that employed on wood or stone. Tracery was produced by different thicknesses of pierced plates laid over each other; leaves and crockets were not carved or modelled, and then cast, but were cut out of thin sheet or plate metal, and twisted up with

pliers; the lines of the stems were either engraved in, or soldered on. By these simple means all the lightness, ease, and sharpness of real vegetation was produced in ancient iron-work".

On this head, Mr. Redgrave, in his admirable Report on the Paris Exhibition, says, as regards the design and the right use of materials, "How diverse, for instance, is, or should be, the whole treatment of cast as compared with wrought metal. Take forged and cast-iron, the lightness and elegance obtainable in the one, contrasted with the necessary solidity and weight of the other; the play of form, fancy, and variety obtainable in wrought-iron, now, alas! almost wholly laid aside for the heavy mechanical common-place repetition of cast-work."

The examination of examples manifesting skilful execution and true construction is calculated to enhance our estimation of the earlier workers in iron; but it must be recollected that, as a principle, the older workers in metal, iron included, first constructed and then adorned; that ornament was not then a primary, but a secondary consideration, in so far as use preceded ornament; but ornament, at the same time, was not neglected, and was not of a "stuck on" kind, but when applied it formed an essential part of the construction. This quality, which shows itself on examining the examples of early iron working, justifies the remark, and strengthens the conviction, that the workers in iron were exceedingly clever artizans; and also that not unfrequently great artists did not think it beneath them to expend their time and talents in working such a humble material. It is known that Matsys exercised his genius upon iron; and the elaborate well-cover which stands in front of the Cathedral at Antwerp, with numberless other works, bear testimony to his skill. In Nuremberg, also, the iron-work which still clings to many an old domicile, demonstrates the master's hand. In every continental cathedral may still be seen the most cleverly designed and executed iron-work; while, in our own country, the railings of the tombs of Henry VII., Queen Eleanor, the hinges and iron-work of Lincoln Cathedral, St. George's Chapel, Windsor, and the Colleges of Oxford, afford equally conclusive evidence.

Even at a later period great ability was displayed; and much interest appears to have been taken in the working of iron, and in its treatment and execution as displayed in making grilles and gates, replete with graceful and flowing lines, with scrolls and flowers introduced; these decorated and guarded the entrances to the buildings erected in the days of Queen Anne and the early Georges. Railings were then elaborated, which partook of the same graceful character; and in the streets and wynds of cities and towns, the signs of the craftsmen depended from iron brackets decorated with tasteful leafage; even the village hostelry had its nicely worked iron brackets, from which hung the sign-board intimating to the passer-by that there was "good entertainment for man and horse" to be had within: these, with other small examples of iron-working, as hinges, locks, door-handles, keys, &c., all give evidence that the blacksmith's art was one which was cultivated with something like enthusiasm, and its professors were

capable of greater things than mending the humble implements of the agriculturists of the period, shoeing the animals of the farm-steads in their vicinity, or the packhorses which traversed the rude roads of the period. The workman who elaborated the ornamental iron-work of the early and latter days alluded to, had his heart in his work, and desired to accomplish it in a creditable manner; not merely to get it done, but done so as to show his ability: he loved the work for its own sake; to this, and to the absence of mere money competition, may, we think, be traced much of the excellence and success of these early examples of iron-working.

Nor is our wonder at the perfection of ancient iron-work diminished, when we consider the limited number and imperfections of the tools which the blacksmith had at his command, and the vast amount of muscular labour which must have been expended beyond what is necessary at the present day. The huge smelting furnaces of Staffordshire did not then exist, and rolling-mills were as yet unknown: as a consequence, bar, rod, and sheet, with other forms of iron now common, could not be procured, and the older workers in this metal had to deal with huge and comparatively formless billets, which they were compelled to beat down at a loss of time and expenditure of strength of which we, in these days of Nasmyth's hammers and Ryder's forging machines, can form no conception. This difficulty of production, it is probable, was not without its advantages, so far as the results were concerned, as there is every reason for believing that the quality of the metal was improved by the hammering, a greater amount of homogeneity and solidity being imparted to it; thereby much facilitating the cold working, which followed after the process of forging had been gone through. Confirmation of this property will be found in the examples formed from thin iron, such as finials, crockets, leafage, and the perforated, bent, and beaten-up work introduced in the iron rails or screens of tombs and altars, and the iron-work generally existing in the cathedrals, churches, and the civil edifices of our own and other countries. These early examples show that the plate or thin metal out of which these were made was left thicker in the centre and thinned towards the two outer edges, which was in turn cut out by filing, chiselling, or saw-piercing, into the form of leaves; after which, these were twisted with pliers when cold, till the desired curvatures were arrived at.

For the better understanding of the method by which leafage or foliated ornament in sheet or plate iron was produced, reference may be made to the illustrations, Figs. 105 and 106, in which the process of the formation of crockets is shown, and which may be described as follows:—The artist having made his design, and well considered the effect desired, first produces it in a flat form (as in Fig. 105), and in full size—preparatory to commencing to bend it up into the form it is intended to retain permanently. When a number of crockets are required, it is well to have a metal mould or templet made like the displayed sketch; and this being laid upon the thin iron, out of which the crocket is to be made, may be scribed round with a brass point, which will leave the outline of the leaves: these are indicated by the letters B, C, D, E, F, G. The superfluous metal is then detached by means of

chisels and saws, or it may be nipped off by means of the press; or the entire blank may be punched out at once in the press by means of a punch and bed. If the press, punch and bed are not employed, the leafage may be corrected by filing. The blank is now in a condition to be bent into form, which is done as follows: It is rendered convex on its external surface, by being beaten from A to G on a hollow anvil; it is annealed, to restore the ductility of the metal, as often as may be required; and ultimately it is made to assume the form of Fig. 106. The curvatures and twistings of the leaves are afterwards given by means of round-nosed and ordinary pliers, in order to secure that regular irregularity, that diversity in uniformity, which charm and delight the eye in handicraft, and contrast so favourably with the monotony of works produced in the die, or by any of the various methods of casting; from which unvarying uniformity, as a result, must necessarily follow.

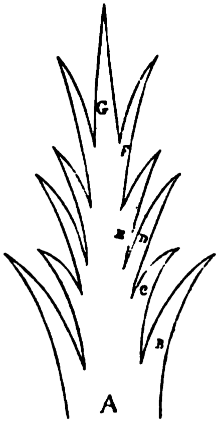


Fig. 105.

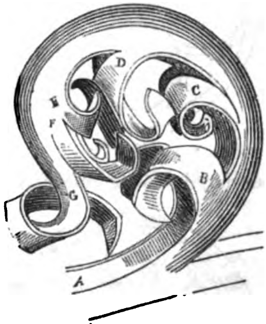


Fig. 106.

In the older works in iron, but more particularly in the external cases of locks, plates, latches, caskets, and similar objects; great sharpness, regularity, and exactness, were secured by perforated plating and overlaying, instead of cutting or chiselling away the iron, in forming the tracery. This will be better understood by reference to the accompanying illustrations, which show the several portions or plates separately, which serve to make up the design of the finished pendant handle represented in Fig. 111. This example is produced by placing over each other several plates of iron, cut out or perforated differently; but which, when placed over each other and riveted together, make out the design. These are shown separately, thus—Fig. 107 shows the foundation plate; Fig. 108, the succeeding one; Fig. 109, the third; Fig. 110, the indented or dog-tooth rim; and Fig. 111, the different plates placed in their proper positions, and riveted together.

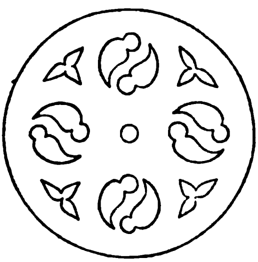


Fig. 107.

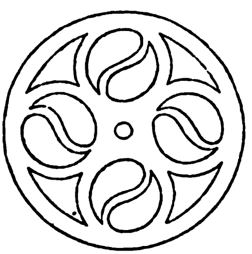


Fig. 108.

It is evident that had such a plate been worked out of solid iron, the time consumed in its construction would have been very much greater; but if cast, it would not have presented the same amount of sharpness, while it would have been quite impossible to have secured the same amount of accuracy in the geometrical details: This mode of construction admits of the greatest possible amount of variation in the details: the beauty of the work may be increased, when desired, by the application of the graving tool or by beading. Care should be taken in this style of work that the several plates, when placed together, and which make up the tracery, should register correctly, and that as much regularity should be preserved as is consistent with the geometrical character of the design.

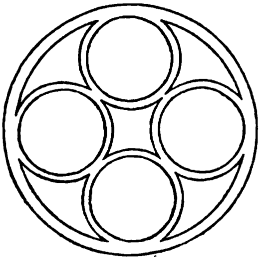


Fig. 109.

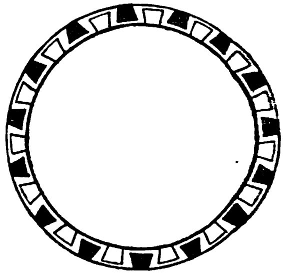


Fig. 110.

Fig. 111.

An additional illustration of the tracery system of ornamentation is shown in the lock, Fig. 112, where the filling up of the principal divisions or compartments, surrounded with a threaded moulding, is produced by perforated plates laid on the box of the lock, and in the angles by ornaments of quatre-foil, of a raised or cut-out kind. The introduction of the crest in the central division is also an ornamental feature, which lends additional interest to the subject.

Fig. 112.

The succeeding example (Fig. 113) is a very excellent illustration of the floriated style of ornamentation. The lock from which the drawing was taken is preserved in the Museum at Oscott. In this example, the foliage which meanders over the two principal compartments of the box of the lock, and along the bolt-like

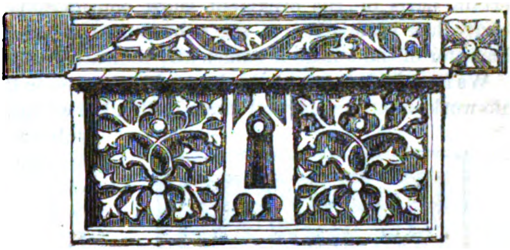


Fig. 113.

moulding, is cut out from plate metal, and so attached to the metal foundation that, while adhering firmly, it is placed at such a distance from the foundation that light passes under the leafage, and a shadow is cast by it. The hint furnished by this example is capable of extensive application to the adornment of similar works or to panels.

Fig. 114.

Allusion has already been made to the skill displayed by the Nuremberg workers in "cold iron." In Fig. 114 we give, as an example of their work, a lock-escutcheon for an "armorie," or "chest;" it was made in 1500, and differs from the preceding examples in so far that though these, like the present, depend for their beauty upon various thicknesses of iron plates laid over each other; yet the present is different, inasmuch as the scroll-work, though separate from the foundation,

has been punched or "beaten up," after being cut out or pierced, so that certain parts of the ornament show considerable convexity. Additional beauty has been given to the subject by the hatching or chiselling. The character of the foliage is sufficiently indicative of its German origin.

We have hitherto dwelt on the working of iron in its plate or sheet condition into works of an ornamental kind; in Fig. 115 we introduce an example of the sculpture form in iron, being, like the preceding example, a lock or bolt for an "armorie." It is of French workmanship of the period of Henry II., 1550, and is chiselled out of solid flat iron in delicate low relief; the lion's head forms the handle for the movement of the bolt, and the lines of the composition are exceedingly graceful. But this example is of an exclusively artistic character, and therefore it does not so directly interest the ordinary iron-worker. It cannot fail, however, to be very suggestive, as it furnishes admirable hints for the filling up spaces in railing, &c. The illustrations which have preceded this will be sufficiently confirmatory of the remark made by a distinguished authority to the effect, "that the lock was a subject on which the ancient smiths delighted to exercise the utmost resources of their art." In churches, locks were introduced with sacred subjects chased upon them. In the twelfth and thirteenth centuries, the locksmith's art produced many works of very remarkable taste and spirit; among others, in the fifteenth century, a tabernacle door was sculptured in iron for the Abbey of St. Loup of Troyes; it is rich in the flamboyant Gothic architectural style of the period, a figure of the Saviour occupying the central panel, with the cup in one hand and the host in the other. All the complex details of this elaborate piece of art-workmanship are admirably executed. The sculptures in iron executed by Plattner in Germany were very celebrated; he decorated the handles of swords and their scabbards, and even carved detached statuettes in iron. The works of Leigeber, born in Silesia, but who worked at Nuremberg, are particularly excellent: among the great

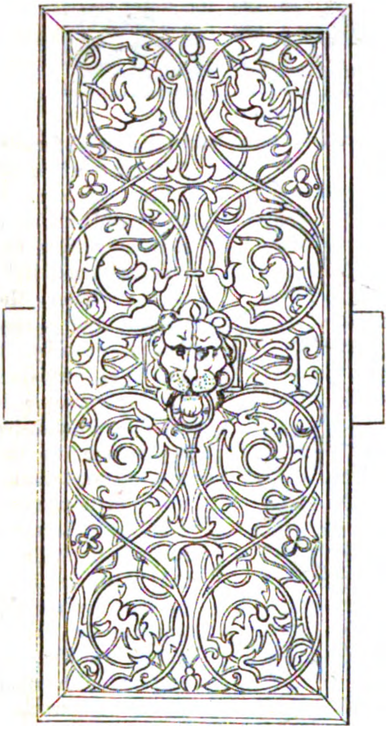


Fig. 115.

works which are attributed to him is an equestrian statue of Charles II. of England as "St. George Slaying the Dragon."

But to return to the work of the artizan, rather than the artist in iron. With the period of the Rénaissance, the art of working in iron, like other quiescent arts, was revived. Locks especially were then carried to such a degree of perfection, and their ornamentation was of so high a finish, that they were looked upon as objects of art, and were moved from one place to another, like any other valuable piece of furniture. Nor were the keys forgotten or overlooked while the locks were thus ornamented: that which is now a bald oval grip or ring, even in locks of an expensive kind, was, in the fourteenth, fifteenth, sixteenth, and seventeenth centuries, elaborated into exquisite designs, filled with tracery or leafage, surmounted with coronets and crests, or perforated into the form of initials These decorations were produced in some instances by means of saw-piercing or perforation, or by chiselling where the scroll-work was in relief. In other examples, in addition to the chisel recourse was also had to the graving-tool; and in others again, the entire finish was dependent upon the clever use of the file. The complicated character of the wards was also another peculiarity in the ancient keys. As illustrations of the general appearance of these, and with the intention of giving some idea of their elaborate style of ornamentation, four illustrations are introduced. Fig. 116 is an example of French or German wormanship, produced by a union of perforations by drilling, chiselling, filing, and engraving. It is supposed to have been made about the year 1350. Figs. 117 and 118 give two representations of the same key.


Fig. 116.

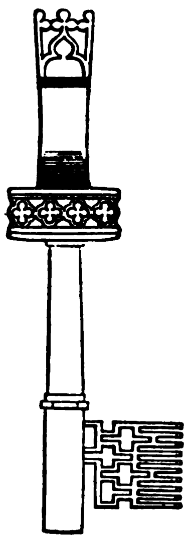


Fig. 117.


Fig. 118.

It is of an exceedingly complex character, depending for its ornamentation on the minute perforations which are introduced; the trefoils evidently form the sides of a hollow square, surmounting a circular disc, which is perforated star or wheel-fashion, and stands on an oval minutely quatrefoil

piece of perforated iron, to which the neck of the key, with its delicate wards, is attached. This example bears date 1400. Fig. 119 is also remarkable for its delicate thread-like piercing, with the graceful arrangement of lines or portions of metal left, the Gothic character of the design being well preserved: it is supposed to be of French or Flemish origin, and bears date 1480. Fig. 120 is an example of Italian or French workmanship of the fifteenth century, and is produced by perforation, the wheel-like grip of the key being formed separately, and inserted into the shank or spindle of the key.

Before the wood-carver took possession of the surface of the doors which guarded the entrances to

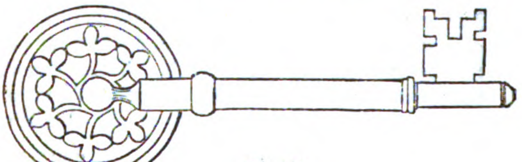


Fig. 120.

ecclesiastical edifices of the day, the hinges frequently covered over the whole face of the door. These hinges were both beautiful in design, and correct in principle. The modern concealed hinge, which is now so generally adopted, is an error. Being constructed on the lever principle, the door may be very easily disconnected from its attachments. Not so the ancient hinges which gracefully expanded themselves over the door, covering its whole width with graceful curves; and being bolted through and to the door in various places, were alike useful and ornamental. Thus the iron hinge-work of the east door of St. George's Chapel, Windsor, presents the most exquisite arrangement of cleverly designed and skilfully executed scroll-work, full of ornamental details. A somewhat modified illustration of the older form of hinges is

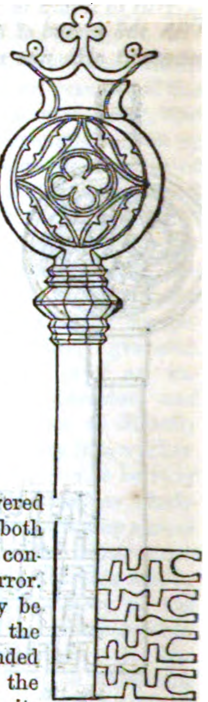


Fig. 119.

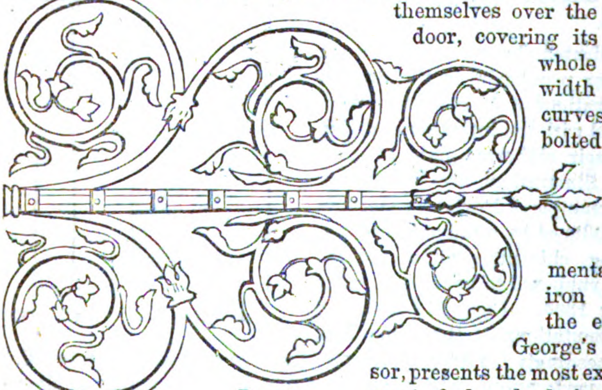


Fig. 121.

given in Fig. 121. The scrolls of these are worked separately, and welded together when each portion is completed, and also attached to the horizontal projecting-bar by welding. The leafage is indented with sunk or raised details by means of punches; and the curved beads which are introduced on the stems are executed when the iron is in a heated state, by sinking it into swages, sunk concave when the beads are desired to be convex, and the reverse when concave.

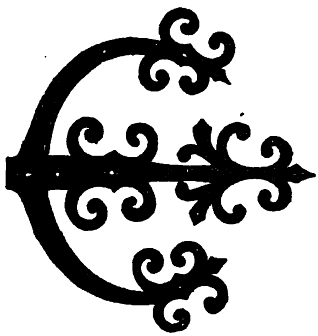


Fig. 122.

In Fig. 122 a design or hinge of simpler character is figured, which is dependent upon its outline only for its ornamental features. In this example, in addition to the assistance afforded by the chisel, the beak of the anvil has been used to a considerable extent, with but little additional assistance from the use of the file.

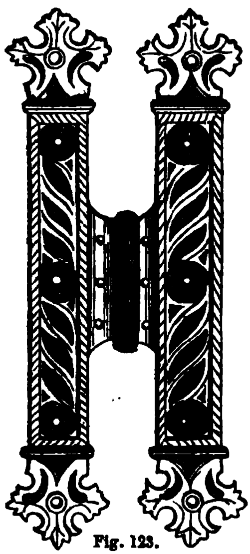


Fig. 123.

The two examples of hinges here introduced may be supposed to be applied to doors plain or flat on their entire surface, and the portions of wood not covered with their foliations being ornamented with rosette, lozenge, octagonal, or other shaped head-nails or studs. In Fig. 123, another form of hinge is introduced, which may be used with excellent effect when the door is framed and panelled. The ornamental features of this hinge are produced in a similar manner to the plate of the handle, Fig. 111, and the lock, Fig. 112,—viz. by a succession of two or more thicknesses of metal, perforated, engraved, chamfered off, and chased, the moulded edge being formed by the file or produced by swaging. By way of rendering our representation of the various kinds of hinges complete, an illustration of a kind very generally used in the furniture of a by-gone period is here introduced, which unites both strength and ornament, as represented in Fig. 124.

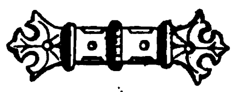


Fig. 124.

So far, however, as hinges of the class we have figured are concerned, there are very few examples which can compete with those on the doors of the Church of Notre Dame, at Paris, more particularly on that of the south portal: these are reported to have been made by Biscornette, a famous

smith of the sixteenth century; but their style points to the earlier part of the thirteenth century. The sculptures, consisting of birds and ornaments, are marvellous productions; they are made of iron of a peculiar quality, produced by a method which puzzled Gaegart, the locksmith to the king, who broke off a portion in order to get some knowledge of it by examination; what he did get, however, he could not use. It is said that Biscorrnette, the smith to whom they were attributed, "melted the iron with incredible industry, rendering it flexible and ductile, and giving it the various forms and scrolls he wished, with a skill which excited the admiration of all iron-workers." Even now, with the increased knowledge of iron and its properties, there are in the minds of many, doubts as to whether they are cast and filled up, or wrought with the hammer. The secret of their manufacture is supposed to have died with their supposed maker, for no trace of the process employed in his work remains. Like most things done at a period when clever workmanship produced results which seemed supernatural to the uninitiated, their maker was supposed to have entered into compact with the doer of all evil to help him. It may, however, be safely affirmed that they are of wrought-iron, made in the thirteenth century; and that all their reputed maker, Biscorrnette, did, was simply to repair them; for it cannot be supposed that a knowledge of the processes for rendering cast-iron malleable existed at that early period. This is another reason for the opinion entertained, that they are made of wrought-iron, skilfully and artistically worked.

But the mediæval workman had other resources, which he failed not to take advantage of, in order to give variety to his design. Aware of the properties of iron, and the liberty which could be taken with it in a heated state, he hesitated not to twist the square bar when formed, and to intertwine round rods together; by these means he produced alike variety and beauty. For the better understanding of this process, two examples are given. Fig. 125 represents a handle formed from square iron. The method by which the twist is produced is exceedingly simple. It is effected by heating the square bar to a red heat; while in this state the one end is held in the square hole of the anvil, or in the blacksmith's vice, while the other is laid hold off by a wrench or key, and twisted round: the result is a spiral as figured. Regularity in the distance of the threads or twists is secured by heating that portion of the bar where the irregularity occurs, the correct part being cooled and kept cool; the wrench is again applied, when, as a consequence, the threads too much apart are gradually made to approach each other, and the irregularity is thereby corrected; the portions of the handles or grips which are to be riveted into the plates, are then bent, in order to insure the required projection. These plates are formed from wrought-iron,

Fig. 125.

thinned towards the edge, the outline being given as described in the preceding paragraph descriptive of the production of a crocket; the grip is thereafter riveted in, and the handle is complete.

In Fig. 126 is shown an example of intertwining round rods or bars. In this example the handle or grip has been produced by placing together side by side, when in a heated state, and parallel to each other, two rods of iron; these being held in a vice, are taken hold of and twisted round until the desired effect is secured; after which a portion is cut off each rod at the reverse end. The single end is bent down to give the projection for the insertion of the hand; the grip thus formed is then riveted into the plate by which the handle is attached to the door.

Fig. 126.

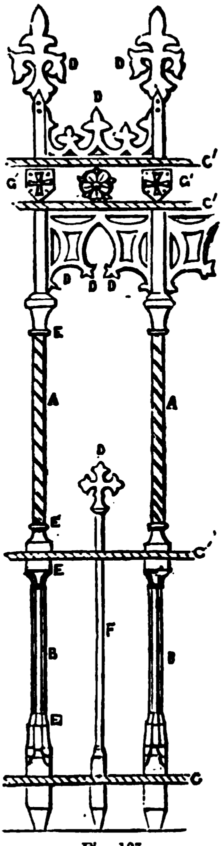


Fig. 127.

It will be readily understood that, by using other forms of bar or rod than those already described in the examples alluded to, great variety and beauty may be given; for instance, angular, oval, reeded, or fluted bars or rods, will much improve the appearance of the handles or railings in which they are introduced. The examples to which attention has been directed have been more particularly formed out of two kinds of iron—viz. bar and sheet. There are, however, other instances in which sheet and bar-iron are made use of together; such cases occur in railings or altar-screens, in which the uprights may be formed from square bars—twisted in certain portions, the corners chamfered off in others. The bars are thereby reduced to an octagonal form, while the capitals and bases get their contour by skilful forging, and are kept correct and uniform by being hammered into swages cut in steel, after the manner of a die, into which the heated iron is driven. In the progress of formation, the transverse or horizontal bars through which the uprights rise may be beaded or otherwise ornamented on their outer edge; elegant rosettes may also be introduced, and the finials or tracery made from sheet-iron. In order to render this union better understood, see Fig. 127, in which this method of using various kinds of iron together is shown. In this example the shaft A is formed separately from square iron, by twisting in the manne r already described in the formation of the twisted handle (Fig. 125).

The capital, and the portion of the bar which rises up through the transverse bars C C, are forged together, the capitals being formed in swages; the ascending portion is slit transversely, and into the slit is laid or placed the finial and tracery formed of sheet-iron, marked D D D, which portions are held there by rivets, which are indicated in the woodcut. The transverse bars C C C receive their rope-looking appearance on the edges also by being swaged. The tall uprights in this example are formed of not less than six parts, and they are united together by screw-pins at E E E. The small upright F is formed of round iron, and its terminal of flat or plate-iron. The hints supplied by this method of construction described will be amply sufficient to show how, by taking advantage of the varieties of iron now manufactured in the establishments of those who deal in this very useful metal, the most complicated design may be successfully realized. In this example, however, there has undoubtedly been a great amount of fitting requisite; the blacksmith and whitesmith have worked together, with the hammerman, the filer, and the fitter. It unites, however, in a remarkable degree, the qualities of strength and lightness, in connection with the power of realizing great beauty of design. The rosettes and shields G G add much to its quaint and peculiar character.

Fig. 128.

Fig. 129.

In Figs. 128 and 129 excellent examples of working in solid iron are shown. The ascending character and intention of these finials are well maintained: they are intended to represent the ornamental terminations of turrets or gables; and, in connection with the pointed style of architecture, they appear to be in admirable keeping. A considerable portion of these have evidently been formed by the use of swages. The details of the coronet in Fig. 128 are sculptured after being forged, as also are the pendant flowers. The same amount of care is evident in Fig. 129, the reverse heart-formed ornament, with its leafage, being a clever exemplification of the iron-working of the period, showing alike good forging, fitting, and tasteful design.

With the period of the Middle Ages, however, all clever construction in iron did not terminate; the spirit which animated them seems to have lingered for a long period, and even to have survived in the workman long after the architect had surrendered all claims to originality in his designs, and adopted the conventionalized treatment of an inferior architecture. It is

most true that floridity and incongruity, in the majority of instances, marked the productions of the latter period; but the construction was quite as complicated, if not more so, in so far as the pieces which made up the work were larger, while the floriated or naturalistic character of the design increased the difficulty attendant upon the manipulating process. In this class of works we only include such examples of iron-working as were made by the blacksmith with the hammer, and of which the scrolls or floriated portions introduced were part and parcel of the workmanship, and not such as may be found on the gates of the Clarendon Printing-Office at Oxford, with other examples produced in the early part of the seventeenth century, where the almost Quatorzic character of the design necessitated the pinning on of the ornaments or scrolls to the skeleton, formed of bar or rod-iron. In this style of construction, the ornaments clung to the skeleton like limpets to a rock: they were attached externally, and they showed that such was their connection; ignoring the principle that the decoration should insensibly, as it were, suggest that it was a unity inseparable from the object of which it formed a part. For the better understanding of the mode of working, two illustrations are here introduced (Figs. 130 and 131), in which the work was produced chiefly by the blacksmith, and in which the ornamental parts naturally take their place. It may be well to point out that Fig. 130 is simply a filling up of a space or panel, where strength is secured by the introduction of the uprights. Fig. 131 represents the intermediate panel. These two examples bear indubitable evidence of the *bona-fide* character of the workmanship, in the hammer marks which may be detected on the surface. Fig. 132 is the flower shown in

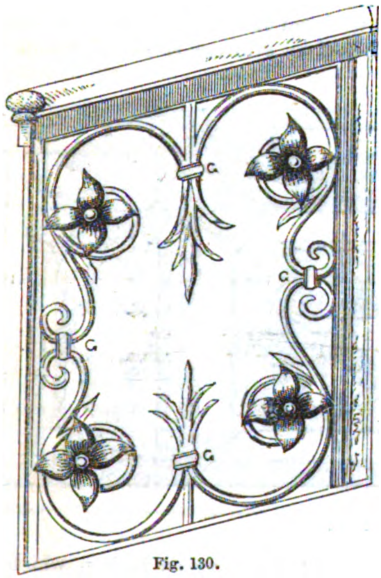


Fig. 130.

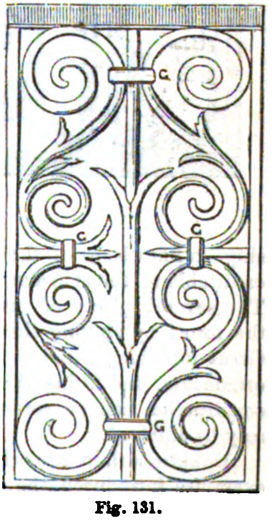


Fig. 131.

section, which was forged separately, and screwed on to the end of the convoluted stem. It will also be observed that connection is made of the several parts formed separately by means of bands or clips, marked G G G. In these illustrations, every portion of the railings was wrought from bar-iron. They stand on, and form the balustrades and railings of, the staircase of a building designed by Inigo Jones, now the council-chamber of a small provincial town in Scotland; and the workman who constructed them was paid at the rate of a groat a-day for his labour. The iron-work of the gates of Gray's Inn and of the Temple Gardens, London, partakes of this style of workmanship.

Fig. 132.

In order to illustrate more fully the methods of construction, or modes of working adopted in ornamental iron-work, an example of "stuck on" ornament is introduced in Fig. 133. This gives evidence of skilful workman-

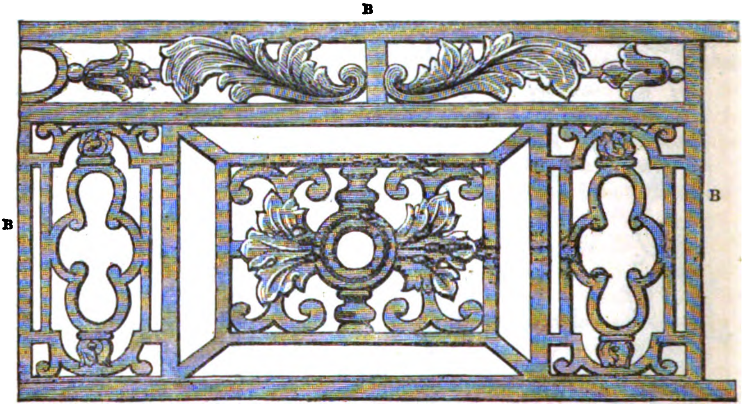


Fig. 133.

ship—a knowledge of the art of "beating up" or *repousse* in iron, which is creditable to the artizans who were engaged in the production of the work. The several pieces of ornament were formed separately, and attached to the frame by pinning them to the already formed portion of the gate (B). Great intelligence and skill have been shown both in the beating up of the ornaments, and fitting them on; but neither the design nor the method of construction can be commended, however much the skill of the workman may be admired.

Doubtless there are other and varied methods of construction; but in the examples introduced, the principles which are involved in ornamental iron-working have been laid down. The use of the tools, and facility in practically working out the art, can only be arrived at by an acquaintance with the labours of the smithy. One peculiarity distinguishes the present age—that is, the division of labour: a principle well fitted to quicken production, but

utterly subversive of the leading characteristics of the older workers in metal, and calculated to destroy all originality in the workman. In those days the artizan worked out the object himself; he made what tools he required—he laboured earnestly and truthfully at his task. But, with all the levelling tendency of the present system, it is evident that with the olden time, the ancient skill and ability of the artizans of this country have not wholly departed, for works in iron have recently been, and are now being, made by Hardman and Co., of Birmingham, and Skidmore of Coventry, which quite equal the best examples of the mediæval period. These, however, have not been produced by ordinary workmen, but by men trained under the inspection of superintendents, who have studied design and construction united. This consideration suggests the propriety of the union of the two elements—the designer, with a thorough knowledge of the principles of design as well as the modes of construction; and the artizan, with eyes educated, to produce the design placed before him. The true test of the skilful artizan is the ability to work out readily whatever design is placed before him in a drawing; and he should ever bear in mind that, however common the material on which he is operating, it is intelligent labour which lends the value to that material. Keeping this ever in view, will be an incentive to his exertions, and make him anxious to excel.

A word or two on the preservation of works in iron may not be out of place in concluding this portion of our subject. The tendency to decay by oxidation in a peculiar degree distinguishes this metal; it may, however, be protected by being covered or painted over with an oleaginous varnish: this allows the natural colour or skin of the iron to be seen, and is usually applied where there is a desire not to conceal the material out of which the work to be preserved is made; iron may also be coated with gold, silver, or copper, by the electro-deposit process. Brunswick and Berlin black varnishes are frequently used to coat and protect iron. Coating by immersion in a bath of melted tin, is sometimes adopted. Galvanizing (a misnomer, however), by means of coating by immersion in melted zinc, has recently been in much favour for the same purpose; and the cheap process of enamelling, known as that of Paris, has also been tried with complete success. For the three last means of protection, it is necessary to clean the skin or outer surface of the article to be protected, by immersion in muriatic acid (spirits of salt); and when this has been done, to dip the cleansed article in a bath of melted tin or zinc, when the complete adhesion of a coating of the melted metal is readily secured. In enamelling, in the early stage of the process, the same method of cleansing is gone through; the article so cleansed is then dipped into a prepared gummy or adhesive fluid; the glass or enamel, reduced by pulverization or grinding to a granulous powder, is dusted upon it, and it is then put into a suitable muffle and placed in a furnace; the result is that after a few minutes' exposure to the intense heat of the muffle, the powder fuses into a uniform glassy coating, impervious to damp, and affording complete protection to the metal object so coated.

Iron Architecture.—Leaving the more minute manipulations in iron, we

now propose to offer a few remarks on the application of wrought and cast-iron to architectural purposes. As we have seen in Mr. Vose Pickett's paper, that gentleman contemplates that a much higher order of beauty, as well as a larger amount of utility, and various other advantages, will result from the use of this material over any pre-existing architecture. The idea, he tells us in his first work, occurred to him while visiting the stalactite caverns of Derbyshire; and in his pages is visioned forth an ideal, which it is to be hoped will ere long be realized: hitherto it has not. The building which accommodated the world's products and the industry of every people at the Universal Exhibition of 1851, was indeed a wonder; elaborated from the blotting-paper sketch of Paxton, by the genius and industry of Fox and Henderson, it directed the public attention to iron architecture by the very great simplicity of its construction, the rapidity with which it rose, gourd-like, from the ground, and the extent of space which it covered: but there its merits ceased; for, saving and excepting its transept, ornamental features it had none; its box-like form gave no relief to the eye. Time, doubtless, had something to do with this. Remodelled, and standing on the heights of Sydenham, with its additional transepts, it must be admitted to approximate somewhat nearer to the ideas of Mr. Pickett; but something greater has yet to be done ere the true capabilities of iron for ornamental architectural purposes are clearly developed. One property, however, has been satisfactorily demonstrated,—viz. its great strength. There were not wanting those who proved clearly and satisfactorily to their own minds, that the Exhibition building of 1851 must necessarily fall—it could not stand; it represented a series of bedsteads standing upside down; a gale of wind would upset it ere a single contribution found its way into the interior: the galleries must fail. These and a thousand other surmises and doubts had a quietus put on them by the result, which far surpassed the most sanguine expectations of the defenders of the much-abused structure. It may be interesting to remind the reader even now, that in this great national work 3784 tons of cast-iron were used, 702 tons of wrought-iron, and that at one period not fewer than 2200 men were employed upon it. There were 2300 cast-iron girders, resting on 1060 columns. The patterns employed were reduced in this work to the smallest possible number; uniformity being the great object aimed at, the "repeats" were of course necessary. This operated in a saving both of time and expense, all essential where rapidity of construction is the point aimed at. The stability of the new architecture having been ascertained, it is matter of surprise that no attempt has yet been made to add to it the graces of ornament. How this may be done, has been very clearly laid down in Mr. Pickett's "New System,"—viz. to increase the number of our appliances, so as to embrace the whole range of metallic substances, and admit the adoption of each of them, in every form in which science may render them available, and by which we may be enabled to realize a higher order of beauty than it is possible to produce in stone; to unite in the highest degree with that beauty, all the necessary utilities required of the art: and this, under many circumstances, at a cost far inferior to that

by which the ordinary effects of masonic architecture are obtained. The greatest objection which could be brought against the material, is its liability to oxidation; but that, as we have just seen, may be counteracted by various means, as electro-coating with copper, or the so-called process of galvanizing or immersing the iron in a bath of melted zinc. The application of barium or carbonate of barytes is also recommended for this purpose; coupled with its suceptibility for the permanent retention of every variety of colour, this material produces all the appearance of porcelain on the surface of the iron, presenting great richness in effect; but enamelled glass is by far the most attractive material for these purposes, possessing, as it does, the additional recommendation of the most perfect and enduring cleanliness.

An uniform and consistent application of metals to the purposes of architecture will, perhaps, tend more than anything that could be devised to encourage the revival of the beautiful art in "wrought-iron work," which was formerly carried to such great perfection. The excellence, however, to which every description of casting is now carried, and the infinitely greater economy attendant upon it, will doubtless render very limited the employment of wrought-iron work in any metallic architecture, unless it be as a partial and superior adjunct, occupying a similar position in relation thereto, as does the art of sculpture to the masonic art.

Independent of casting, various other processes in the manufacture of metals will, both in regard to effect, utility, and economy, be found highly useful. Amongst these may be enumerated the rolling and corrugating of sheet-iron, which may, with great advantage, be applied to various internal purposes; stamping or embossing in the various forms required for the decorative features of the art, whenever the processes of working or casting prove too difficult or expensive to be obtained; every description, likewise, of woven or wire-work, whether in the form of gauze for a lining of certain parts and for the purpose of ventilation, for the admission of, or for subduing the effects of light, force of the sun's rays, &c.; or in any other form (and they are multitudinous) in which it may be worked by the hand, and employed for the purposes of art.

Copper, and more especially brass, will also be found a highly useful constituent of architecture in conjunction with iron. The facility and beauty with which every variety of form may be produced by means of embossing as well as of casting in this metal, and the advantages it possesses of assuming, and, when lackered, of permanently retaining, a colour and polish similar to that of gold, together with the cheapness of its production, render its extensive introduction into the interior of edifices an object highly desirable whenever the practice of "a legitimate metallurgic architecture" shall be established.

Japanning and enamelling in various colours, &c., whilst forming an excellent preservative, is also a familiar appendage of metallic substances in manufacture, and is therefore consistently admissible for the purposes of internal decoration. In fact, almost every description of paint, as well as the majority of colours, being composed of metallic substances, are

the legitimate materials of a "metallurgic architecture." The occasional introduction of variously cut and coloured glass, after the manner of gems in jewellery, is also perfectly admissible into this art, whenever superior richness or resplendency of effect is desired.

From their affinity with metallic properties, as well as their greater warmth and dryness, in addition to their superior harmony in effect, a preference will naturally be given to vitreous and similar substances for the purposes of pavements, &c.; amongst the most useful of these, the numerous descriptions of encaustic and other tiles, of asphaltic and other compositions, may be enumerated. Hitherto the suggestions which the preceding remarks necessarily evolve have not yet borne fruit; but there is some satisfaction in knowing that recently attention has again been directed to the subject by the Ecclesiological Society, who, deeming it of some importance, in March last, besides putting themselves in communication with Mr. Vose Pickett, applied to two eminent contractors for tenders to build an iron church. The economy of iron, in connection with superiority of ornament, will at once be evident, when it is shown that, while the same design executed in stone would cost upwards of £7000, Messrs. Skidmore and Son, of Coventry, agreed to execute the same in wrought and cast-iron united, for the sum of £2500, and Messrs. Noughton and Bevan, of Gravesend, for the sum of £2150. The remarks accompanying Messrs. Skidmore's estimate were of so intelligent and explanatory a character, that we place them *in extenso* before the reader:—"If iron is to be considered a material of our age and locality, and to be used as our forefathers used every material of their day, giving it its natural expression, adding art and beauty to constructive form, it would be unlike their actions and unworthy of ourselves to use a new (for, considering the facility of its production in our day, and its great and extending use, it may be considered as a new) material only as a cheap expedient, instead of giving to it that development in Christian art of which it is so capable.

"In furtherance of these views, I would suggest the use of geometrical forms of iron, the constructive supports of the walls filled in with marble of various colours; as also carving or ceramic products for the same purpose. The interior would afford ample scope for carrying out that floral treatment, so much used in the fourteenth century. The iron, also, would require coating with pigments to preserve its surface, and would form a ready means of illumination. The renewed use of crystals and gems, as in ancient metalwork; the use of enamels, which present facilities would permit to a greater extent even than in ancient work; the covering the wall-surfaces with tapestry having historical subjects, reredos of brass or silver and brass combined, are also objects to be aimed at."

In the design for this church, the simplicity of the construction is rendered very apparent; the frame-work is of cast-iron, and fitted in the interior with a tracery of thin sheet-iron, perforated into ornamental forms; the columns are of cast-iron. The clerestory windows are divided into lights by cast-iron pillars with spiral shafts, having plain capital and base, in keeping

with the architectural design. The walls are formed of double iron, placed some inches apart, and the interstices packed with felt and sand; the beautifully designed rood-screen, with the foliated or ornamental cross surmounting the apex, and the decorated altar-rail of hammered iron, add considerably to the beauty of the interior. Externally the appearance of the elevation is not so attractive; its plainness is, however, relieved by the belfry, with its perforations, its crockets and ornamental cross, and the iron filling up of the walls of the porch. Altogether, the admirable designs of Mr. Vose Pickett, and the example now under consideration, lead us to think that there is a great future for iron architecture, when the capabilities of the material are taken advantage of, and that encouragement vouchsafed to it which the importance of the subject demands.

CHAPTER XXVII.

COPPER AND ITS ORES; THEIR SYNONYMES, PROPERTIES, AND USES. PROCESSES FOR CLEANING ORES.

COPPER is one of the six primitive metals; it is the lightest of all except iron and tin, and the hardest of all except iron. It mixes in fusion with both gold and silver, to both of which it forms an alloy. It is very liable to rust; all kinds of salts, all unctuous bodies, and many other natural substances subsequently to be described, are solvents for it. It is remarkably sonorous, being the basis of all the compound metals in which that quality is sought for; and its divisibility is so great, that a grain dissolved in an alkali will give a sensible colour to 500,000 times its weight in water. After hammering, its appearance is silky, and its lustre seems to be increased. Heated to fusion, it absorbs oxygen, oxidizes at the surface, and becomes covered with a black crust; and it may be converted into suboxide altogether by a strong heat in the muffle. At a high white heat it burns with a greenish coloured flame. In dry air, copper is unchangeable; in moist air, and in presence of carbonic acid, sulphuretted hydrogen, or other acids, it becomes dark, and assumes a bronze colour.

Copper is a red-coloured metal, with a specific gravity of 8·78, which may be increased to 9·00 by hammering, or one-seventh heavier than wrought-iron. It is an excellent conductor of heat and electricity. The tenacity of cast-copper is sufficient to support a weight of 19,000 lbs. to the square inch, or rather more than half as much as good cast-iron. When heated, it rapidly loses strength, and at a dull red-heat is little more than half as strong as at ordinary temperatures. It melts at 1995° of Fahrenheit's thermometer, according to Daniell, but Plattner and Guyton Morveau make it 2143° and 2204° respectively. By numerous experiments the author has determined, that at 2100° copper coin is very fluid, from which circumstance it may be inferred that the fusing-point is within a few degrees of 2000°.

Synonymes: Cuprum, *Lat.;* Cuivre, *Fr.;* Kupfer, *Ger.*—The name of this metal is said to have been derived from Cyprus. By the alchemists it had the application of "Venus," from a supposed relation to the planet of that name. It has been known from the most remote antiquity, having been largely employed by the ancients for weapons and utensils long before the art of making iron and steel was discovered. It is probable, from recent discoveries made on the American continent, that it was obtained principally, if not entirely, in the metallic form; for amongst the North American Indians weapons of copper were found, which have subsequently been traced for their origin to extensive deposits of the metal in a native state.

On the shores of Lake Superior, in North America, masses of the metal have been found, varying from a few pounds to more than eighty tons in weight. The produce of this district in 1855, consisting principally of the

metal, amounted in value to upwards of two million dollars. Mr. Henwood, who visited these mines in that year, speaks of having seen the miners chipping off the metal with sharp steel chisels; but so tough was it, that it curled up like shavings. Much difficulty has been experienced in working these mines, on account of the extraordinary amount of labour requisite for cutting up these masses of metal.

It is frequently found alloyed with silver, or in dendritic masses, whose branches are half silver and half copper, both of brilliantly bright metallic lustre; the silver, for the most part, having a frosted appearance.

A large vein has lately been found at Haerlech, North Wales. It is of frequent occurrence in small quantities in most of the copper mines in Cornwall. In the mining department of the Great Exhibition of 1851, there was a very large specimen of it from the Trenance Mines, in the Lizard district. It was a portion of a mass thirty feet in length, taken from a lode worked in the serpentine. It is also found in Sweden, Hungary, Siberia, and Brazil. It is ordinarily associated with granite, gneiss, clay-slate, mica-slate, serpentine, steatite, quartz, carbonate of lime, sulphate of lime, and sulphate of barytes.

It occurs crystallized, in octahedral and other forms, in ramose, dendritic, and amorphous masses; but more frequently in plates, leaves, or grains of a brownish-red colour, ductile and malleable; but by fusion these properties are rather injured than improved.

Pure copper in mass is hard and sonorous, but capable of being cut with a knife. According to Moh's scale, introduced in "Chapman's Mineralogy," its degree of hardness is 2·5 to 3, that of tin being 2, and lead 1·5. Its hardness is increased by hammering, rolling into sheet, or drawing into wire. If either of these processes be repeated sufficiently long, the metal is rendered extremely brittle; but its tenacity and malleability may be restored by a process of annealing, to be hereafter described in treating of the uses of the metal.

A fracture of the metal in a soft state is red, shining, granular; and if very soft metal, it is crystalline. When hard, its fracture presents a fibrous lightish-red silky appearance. The increase of specific gravity from 8·78 to 9·0 by hammering was supposed to arise from the condensation of the particles of the mass; but when copper is melted in contact with the atmosphere, it absorbs oxygen, and becomes slightly porous. This absorption is prevented by fusion under common salt. The density of the metal so fused has been found to be 8·921; and after being subjected to a pressure of 300,000 lbs., it has been increased only to 8·930. The difference is so slight that it is probably owing to a diminution of the spaces still remaining, rather than to an approximation of the particles of the mass to each other. It has a disagreeable taste and smell. It is an excellent conductor of heat and of electricity. Its power of conducting heat is 898, taking gold at 1000; iron being 374, and lead 179.

A bar of copper heated from 32° Fah. to 212° is lengthened about 1-580th part, while iron is extended only 1-810th.

Taking its power of conducting electricity at 100, that of silver will be

136·25, of gold 79·79, of iron 17·74, so that it will be seen that it is one of the best conductors of electricity.

Copper in a finely divided state, if pressed together and made red-hot, as in Wollaston's process of preparing platina, may be welded together into a solid mass, provided it has been soaked in oil previous to ignition, in order to prevent oxidation. It expands in solidifying. The addition of 0·1 per cent. of potassium, zinc, or lead, will prevent expansion in cooling. It boils at an intense white heat; but is not volatilized. Exposed to intense heat in a close vessel, it incurs no sensible loss of weight.

In a finely divided state, placed on ignited charcoal, it burns like tinder; if on being lighted it be put into an atmosphere of oxygen, the combustion becomes very vivid, the metal being converted into the state of protoxide.

Lengthened exposure of the bright metal to a humid atmosphere, causes its oxidation, and it becomes covered with a green carbonate of copper, commonly, but incorrectly, termed verdigris. Heated to redness in contact with the air, it oxidizes, and the scales of the oxide fall off. With care, at a low red-heat, bars of it may be worked by the smith in the same manner as iron. Unlike iron, copper will, under no circumstances, decompose water, not even with the intervention of acids. It is soluble in acids, but mostly so in the oxygenating acids.

In nitric acid it is rapidly dissolved with the evolution of nitric oxide, which is converted into the ruddy violet fumes of nitrous acid on coming into contact with the atmosphere. It is dissolved in concentrated sulphuric acid on the application of heat, with the evolution of sulphurous acid gas, and the production of sulphate of copper.

Muriatic acid, strong or dilute, dissolves it but slowly, and only with the access of air. Strong solutions of the alkalies have no action, because they contain no atmospheric air; but weak solutions, especially of ammonia, with the access of air, rapidly dissolve it. The solutions of copper are distinguished by their green or purple colour. That of ammonia is particularly remarkable for its deep purple colour.

The oxides of copper obtained from solutions in acid by neutralization with alkalies, may be readily obtained perfectly pure, in the metallic form, by passing hydrogen over them in a close tube exposed to heat. A heat below redness is sufficient to cause the decomposition of the oxides with the production of metallic copper and of water. The metal may also be obtained by putting zinc or iron into solutions of it in acid.

The uses of copper in the arts and for industrial purposes are exceedingly numerous. Sheathing and fastenings for ships, and marine engine building, consume a large quantity annually. The copper-smith, plated-ware manufacturer, locomotive boiler-maker, and engine-wright, likewise work up considerable quantities, principally as bar or sheet copper; while the mint is a large customer for the copper coinage. But the articles made of the metal itself are few in comparison with the numberless forms in which it appears as an essential ingredient in mixture with other substances.

The gold and silver coinage is alloyed with copper; gold jewellery is

alloyed with it in less or greater quantity; imitation gold is composed principally of copper; while silver-plate is alloyed with it, and imitation silver composed to the extent of two-thirds of the same metal. Chinese gongs, bells, reflectors for telescopes, statuary bronze, gun-metal, and brass, contain copper as a preponderating ingredient.

The most brilliant green paints are a compound of copper with other substances; other combinations produce blues of great value. In one or other of these forms it is largely used in enamel painting and colour-making.

Copper is one of the most abundant metals. It is found widely diffused throughout organic and inorganic nature. Although all the salts of copper are poisonous, both to animal and vegetable life, it has been found in the ashes of plants, in the blood of man, and in the conger, common crab, snail, oyster, mussel, &c. In the oyster it has sometimes occurred in sufficient quantity to make it, as an article of diet, very deleterious. It is found principally mineralized by combination with sulphur and arsenic.

With sulphur and sulphuric acid, copper forms sulphurets and sulphates of definite composition; arsenious and carbonic acid also appear to combine with it in atomic proportions. With iron, gold, silver, lead, tin, zinc, and some other metals, it forms mechanical mixtures and chemical alloys; and the same is believed to be the case with arsenic. Sulphurets of these metals appear to unite with sulphurets of copper in definite proportions.

Copper Ores.—The ores of copper are found principally in the primary and the lower transition rocks, in veins varying in width from a few inches to several fathoms, several miles in length, and extending in depth beyond the limits ascertained by mining.

Red Oxide of Copper (ruby copper, suboxide of copper) is of a bright red colour, sometimes exhibiting a grayish metallic lustre on fracture, which disappears on reducing it to powder. Specimens of this variety are found in Cornwall, France, Saxony, Siberia, Brazils, and the Lake Superior district. Specific gravity, 5·80 to 6·00. When pure, it consists of two equivalents of copper with one equivalent of oxygen; or, decimally, of—

Copper	88·78
Oxygen	11·22
	100·00

It has often been found in Cornwall, beautifully crystallized, with a most brilliant lustre, translucent on the edges of the crystals of a rich ruby colour. A very large mass of it in the amorphous form was shown in the Great Exhibition, sent there from the Redruth district, Cornwall.

Black Oxide of Copper (peroxide of some, protoxide of other writers) occurs, of a velvety black colour, in granular masses of a gritty consistency. It is found in small quantities in several mines in Cornwall; in larger quantities in France, Siberia, and the South Australian mines; and in greatest abundance in the Lake Superior district. The composition of pure black oxide of copper is one equivalent of copper to one of oxygen: or, decimally, of—

Copper	79·83
Oxygen	20·17
	100·00

The richest pieces mined yield about 45 per cent. of the oxide; the remaining portion of the ore consisting of iron, sulphur, and earthy matters. It is nearly always accompanied by other ores or copper, such as the sulphurets and arseniates. The red and black oxides are distinguished from other ores by their ready solubility in hydrochloric acid.

Muriate of Copper (oxychloride of copper, atakamite) is of a green colour, crystallizing in prisms of a specific gravity of 4·40 to 4·50. It is a rare mineral, having been detected in notable quantities only in Southern Italy, Saxony, and the Atakama Desert, in the neighbourhood of Chili and Peru, in South America. In the latter country it exists in considerable quantity, decomposed into a green sand; but the absence of facilities for transporting it to market has operated against extensive mining. Its constituents are chlorine, copper, oxygen, iron, and water, in varying proportions, the following being the composition of one specimen:—

Chlorine	16·00
Copper	57·60
Oxygen	11·34
Water	14·16
Iron	·90
	100·00

Carbonate of Copper (malachite, mountain green, green carbonate). This variety of copper ore occurs of various shades of colour between green and blue, crystallizing in rhomboidal prisms of a specific gravity of 3·2 to 3·8; but more commonly in reniform, mammillated, or botryoidal masses. Formerly it was obtained almost exclusively from the Siberian mines; but of late years the South Australian mines have produced very large quantities, and the American mines yield some good specimens. It is also found in Cornwall. Its constituents are oxide of copper, carbonic acid, and water, in slightly varying proportions. The analysis of a clean specimen of green carbonate gave—

Oxide of copper . .	72·20
Carbonic acid . .	18·50
Water, &c. . .	9·30
	100·00

This is equal to a produce of 57·7 of metallic copper. The admixture of earthy matter results in the average produce falling considerably under this for large parcels of ore. A specimen of blue carbonate, when analyzed, gave—

Oxide of copper . .	69·08
Carbonic acid . .	25·46
Water, &c. . .	5·46
	100·00

Many of the carbonates of this class have an exceedingly beautiful appearance, when cut and polished to show the different tints of the successive concentric rings. Of late years it has been applied to a large extent to ornamental purposes, for which the large masses are eminently adapted. For this purpose it has been principally obtained from Siberia, where masses of half a million pounds have been found. Most magnificent articles of *virtu* made of it were sent to the Great Exhibition by the Russian Government. It is only since the discovery of this mineral in large quantities in the Australian mines, that it has become a regular article of manufacture in Great Britain. Fine compact pieces of it, cutting solid, fetch as much as a guinea per pound.

Dioptase copper, or emerald malachite,—a beautiful but rare ore, consisting of oxide of copper, carbonate of lime, silica, and water, in varying proportions,—is, perhaps, entitled to precedence as the most beautiful ore of copper.

Anhydrous Carbonate of Copper (mysorine) is a carbonate of a dark-brown colour, generally shaded with green or red, and of a conchoidal fracture. It is a rare mineral, found only in the province of Mysore, in India. In addition to oxide of copper and carbonic acid, it contains peroxide of iron and silica, nearly in the following proportions:—

Oxide of copper . . .	61·30
Carbonic acid . .	16·86
Peroxide of iron . .	19·69
Silica	2·15
	100,000

Sulphurets of Copper.—The sulphurets form the most abundant deposits of this ore in the Old World. They are a numerous class; comprising simple and compound sulphurets, and form the most important metallurgic species of the ore.

Sulphuret of copper (vitreous copper, kupferglanz) breaks with a steel-gray, or grayish black metallic lustre; crystallizes in rhomboidal forms of a specific gravity 5·60. It is met with in several localities in Cornwall, Devonshire and Cumberland, in Saxony, Siberia, Australia, and America. Its constituents are copper and sulphur. In the ore, small quantities of iron and varying proportions of silica occur, as is seen by the following tabular statement of a very rich specimen:—

Copper	79·30
Sulphur . . .	18·96
Iron	·74
Silica	1·00
	100·00

In other varieties of this ore, antimony plays a very conspicuous part, selected specimens yielding nearly 40 per cent. of this metal, with scarcely a trace of iron and silica.

Sulphuret of Copper and Iron (yellow copper ore, or copper pyrites) appears to be the most common ore of copper in England. It is mined in North and

South America, the East and West Indies, China, Australia, and Africa, and the majority of the European States. The extensive copper-mines of Cornwall and Devon are principally wrought on deposits of this ore. Anglesea, in Wales, formerly produced large quantities; and Wicklow, in Ireland, has long been celebrated for its cupreous deposits. Cumberland, Yorkshire, Scotland, and a few other localities, are found to contain less profitable deposits. When pure, the fracture is brass-yellow, with a metallic lustre; it crystallizes into tetrahedra and octahedra; specific gravity, 4·20. It is a compound sulphuret, consisting of one atom of sulphuret of iron with one atom of sulphuret of copper; or decimally of

Copper . . .	34·20
Iron	30·25
Sulphur . . .	35·55
	100·00

Copper pyrites dissolves slowly in nitric acid; but is readily soluble in nitro-muriatic, with separation of sulphur, provided the operation has not been too long continued.

In other varieties of sulphurets, the relative proportions of copper, iron, and sulphur vary considerably, occasionally producing very beautifully coloured ores. The peacock-ore, a very handsome variety, so called from presenting in its fracture the colours of the rainbow, or peacock's tail, is frequently met with in Cornwall. It differs from the common pyrites in containing a minimum amount of sulphur, and larger per-centage of copper. The variation in the composition of different specimens may be seen by the following analysis, where No. 1 represents a poor, and No. 2 a rich ore of this class:—

	No. 1.	No. 2.
Copper . . .	38·2	69·5
Iron . . .	32·7	7·5
Sulphur . .	29·1	23·0
	100·0	100·0

Gray Copper Ore is found to a considerable extent in Cornwall and other cupreous districts. It is of a steel-gray colour, metallic lustre, and crystallizes in forms derived from the tetrahedron; specific gravity, 4·80 to 5·20. The analyses of two rich ores from mines in Cornwall gave:—

Copper . .	47·90	46·21
Iron . . .	14·10	9·34
Arsenic . .	11·40	19·03
Sulphur . .	21·60	25·42
Silica . .	5·00	—
	100 00	100·00

Other ores of this class contain notable quantities of antimony, and lesser quantities of zinc and silver. This is more especially the case with those of

Saxony, Hungary, Mexico, Peru, and other foreign districts where this ore occurs in quantity. The composition of a Hungarian ore was—

Copper	41·22
Sulphur	27·23
Antimony	12·63
Arsenic	10·20
Zinc	3·60
Iron	4·72
Silver	·40
	100·00

The other principal compounds of arsenic and copper may be summed up as—1st. Rhomboidal arseniate of copper (Erinite, kupferglimmer), of an emerald-green colour, and specific gravity about 4·00. Constituents—oxide of copper 59·36, arsenic acid 33·84, water 5·02, alumina 1·78 = 100. 2nd. Octahedral arseniate of copper (lens ore, broconite), of a blue colour, and specific gravity 2·6 to 3·3. It consists of oxide of copper 50·0, water 35·72, arsenic acid 14·28 = 100. 3rd. Prismatic arseniate of copper (olive ore, olivenite), of a dull olive-green colour; of specific gravity, 5·00 to 5·20. Its principal constituents are, oxide of copper 51·00, arsenic acid 45·00, with minute quantities of phosphates. The above three varieties of areniate of copper are found in several of the Gwenap mines in Cornwall, as also in other districts.

Chromate of copper and lead is a rare mineral, found in Siberia; and by the preponderance of lead, belongs properly to the ores of that metal. Plumbiferous gray copper ore also belongs to the ores of lead, its composition being nearly as follows:—Lead 40·8, copper 12·6, antimony 26·3, sulphur 20·3 = 100. The hydrated silicate of copper (chrysocolla), of a bluish-green colour, and specific gravity 3·2, consists of oxide of copper 50, silica 26, water 17, carbonic acid 7 = 100. Stanniferous copper ore (tin pyrites, bell-metal ore), a rare mineral, is found only in Cornwall and Mexico. Its constituents are copper 30·33, tin 26·76, iron 12·10, sulphur 30·81. Bismuthic sulphuret of copper is of a dark gray colour, consisting of copper 37·10, bismuth 48·74, sulphur 14·16 = 100. Seleniate of copper is of a silver-white metallic lustre, consisting of nearly 62 per cent. of copper to 38 of selenium. It has been found only in Sweden, and in the mines of that country in very limited quantities. Uranium is a constituent of several copper ores, found in the west of Cornwall; and careful analysis demonstrates the presence of several other rare minerals.

The phosphates of copper are principally of interest to the mineralogist; the quantity mined in all cases is too small to render them valuable in a metallurgical sense. Very fine cabinet specimens are obtained from the American mines. Phosphate of copper is of an emerald-green colour, containing oxide of copper 65·0, phosphoric acid 28·0, water 7·0 = 100. The hydrous phosphate of copper consists of copper 63, phosphoric acid 22, water 15 = 100.

Cleaning the Ores.—This is commenced in the mine by rejecting such

portions as appear worthless, and sending them up separately from the ore, or stowing them away in any vacant place below. In determining the value of the stones broken, the miner trusts to his eye and the apparent heaviness as to their being sufficiently rich; but frequently the whole of the stuff broken off the lode is sent up for dressing. When working on poor ground, however, the nice discrimination observed in selecting the mineralized portion in the imperfect light afforded by his candle, is acquired only by long experience. Cases have occurred where valuable minerals have been thrown away as worthless; as an instance, it may be mentioned that in the early tin mines the tinners were accustomed to throw away the copper ore, now eagerly sought after. This has frequently been adduced, as showing the want of information among the miners of that period; in reality, however, it nowise affects his shrewdness and general character for intelligence. At that period he was paid for mining tin ore, a ready sale for which existed from time immemorial. Had he dressed the copper ore and offered it to the tin-buyers, they would not have purchased, and he would have lost in a pecuniary sense. When the advance of metallurgical science had pointed out its character, and purchasers appeared for the apparently worthless mineral, the miner's skill enabled him to supply the demand which sprung up; but it was no part of his province to extract, at a great cost, a mineral for which there did not appear to be a sale.

At the surface the cleaning is recommenced by separating the larger stones from the small stuff, for "spalling." This operation, which is commonly done by men, consists in breaking the large stones into pieces of two or three pounds weight. The resulting broken mineral is divided into three parcels, viz. "best ore," "poor ore," and "attle" or worthless matter, which is discharged from the dressing-floors. The "best ore" of this operation, with the smaller fragments of the pile, are "cobbed" by young females—a repetition of the spalling process—reducing the pieces still smaller; they are again sorted into three parcels; but the best ore is conveyed direct to the crushing-mill, or placed aside for that purpose. The poor ore of the spallers is subjected to the cobbing process, and is similarly divided. If careful dressing is pursued, the poor ores of the several cobbers are again sorted into the three divisions. The ores of the miner, other than the smallest, are thus reduced to two qualities, and a considerable portion of the matrix rejected in this early stage. The treatment of the two qualities of ore is essentially different.

Formerly the best ore was invariably crushed under flat hand-hammers, or cobbling-hammers, on iron plates or old stampheads, by females; and in mines producing but little ore, this method is still pursued. The cast hammer has a square face, and weighs about 4 lbs.; with this primitive instrument the ore is crushed so as to pass through sieves of four to sixty-four meshes or holes to the square inch. If the ore is of more than average richness, it is broken to pass through the fewer meshes; if poor, to pass through the larger number.

Crushing-Mills or Grinders.—Mines producing large quantities of cop-

per ore generally have a mill for grinding them expeditiously and cheaply. These mills are a modern invention, having been introduced to the Cornish mines about thirty years since. When properly constructed, and worked up to their full power, they materially reduce the cost of dressing the ores, and allow of comparatively poor ores being successfully prepared for market. They commonly consist of a pair of chilled cast-iron rollers of adamantine hardness; the one about twenty-four inches diameter and the same in length, the other somewhat smaller and shorter; each roller is mounted on a wrought-iron axle, which is connected by spur-gearing with the crank-shaft of a steam-engine, or some other prime mover. The rollers revolve in brass bearings in a massive cast-iron framing; the small roller is maintained in its position against the larger by weighted levers, which allow it to recede when any substance harder than usual intervenes (Fig. 134). Commonly the rollers are pressed into contact with a force of sixty tons. Over the rollers is constructed a suitable hopper, into which the ores to be ground are delivered from the tram-waggons. The ground ore falls into a divisional hopper, by which it is conveyed into one end of a cylindrical riddle, revolving rapidly in a diagonal direction. Two riddles are employed side by side, the one with coarse and the other with fine meshes; by altering the division in the lower hopper, either or both of the riddles may be worked.

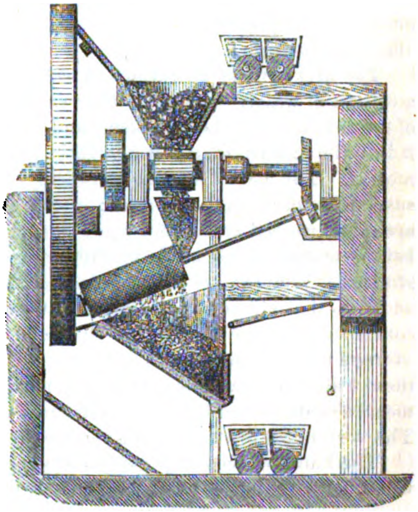


Fig. 134.—Mill for grinding ores.

The crushed ore passes through the meshes of the riddle, and is collected into a third hopper, whence it is let off, as required, into tram-waggons. The unreduced portion passes down the riddle, and is delivered into the diagonal buckets of a large internal wheel, called a raff-wheel, constructed of wood, and revolving rapidly, by which it is elevated above the rollers, and again delivered into the hopper for re-crushing.

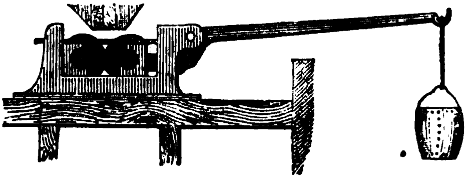


Fig. 135.—Showing mode of applying pressure on rollers.

A mill of the dimensions here given, making twelve to fourteen revolutions per minute, will grind

six to ten tons per hour, according to the hardness of the ore and the fineness or roughness of the meshes in the riddle; and a steam-engine of thirty to thirty-five horse-power is required to drive the mill effectively. The rubbing part of the rollers is worn out by the action of three or four weeks' crushing. The best ore is passed through the coarse riddle, and taken from the crusher to the pile for sale. Poor ore is passed through a riddle with small meshes, and from the crushing-mill is taken to the dressing-floors, where it undergoes a succession of operations, in order to partially free it from extraneous matter, thereby increasing the average percentage of metallic copper before offering it for sale.

The first of these operations is technically known as "jigging" the ore in a cistern of water. Formerly this was universally done by filling a quantity of ore into a copper-bottom sieve, and then taking it by the handles, plunging it into the cistern, giving it a jerking, and at the same time a semi-rotatory motion. The act of forcing it quickly into the water, causes a momentary suspension of the lighter pieces; after a few repetitions of the process, these are found ranged at the top, while the largest fragments of ore sink to the bottom of the sieve, nearly in the order of their specific gravities. A thin stratum is now scraped off the top and thrown aside, a fresh quantity of ore added to that already in the sieve, and the process repeated. The process is continued until the contents of the sieve consist almost exclusively of ore of average richness, when it is delivered to "pile." In the bottom of the cistern there will have been collected the fine particles of ore which passed through the meshes of the sieve: the water is drained off, and this is also carried to "pile." The very finest ore held in suspension by the water is collected and cleaned.

The hand process of jigging is applicable only to small quantities of ore; when large quantities are to be washed, machinery driven by steam or water-power is substituted for the hand sieve; and the manual labour employed is confined to filling and skimming. Machine-wrought jiggers work on the same principle as the hand apparatus. The wooden cisterns are larger, being 6 feet long, 4 feet wide, and the same in depth, arranged endwise along a narrow shed. At each end is a wooden framework 6 feet high, supporting a wooden frame lever, the short forked end of which projects over the cistern, and is connected by iron suspension straps to a square sieve. To the other and longer end, the common proportions of which range from 18 inches to 11 feet, an iron rod is attached in connection with a small crank on the body of a longitudinal shaft, which is driven at a quick speed. A second lever, with a rod reaching to the attendant, serves to lift the sieve through the slotted suspension straps whenever a cessation of the motion is required. The sieves measure 4 feet by 2 feet wide, and 9 inches deep, strengthened by iron bands and numerous laths across the bottom to support the wire-work. Iron sieves are rarely admissible, owing to the destructive action of the mineralized water; and brass lasts a shorter period than might be imagined. The size of the mesh is regulated by the mesh of the revolving riddle of the crushing mill; if the latter is four to the inch lineal, the sieve will contain five or six. An end view of a jigging apparatus is given in Fig. 136.

The ore carried away by the water is partly collected by passing the current to a circular buddle. At first it passes into a wooden cistern, in which revolves a short cylindrical block, having on its periphery a number of stout projecting spokes. In its revolutions the spiked cylinder agitates the liquid, which escapes by a short trough into a second cistern containing a similar revolving block, armed with a number of projecting paddles. This apparatus still further agitates the passing mixture. From the second cistern it flows by a short trough into the upper end of a cylindrical riddle, revolving in an inclined direction, and discharging at the lower end, into a suitable receptacle, any pebbly matter. The fine particles fall into the cistern under the riddle, and are conveyed by the current to the centre of the buddle. A plan view of the cylinders and riddles, showing also the mode of driving them by bevel gearing, is given in Fig. 137.

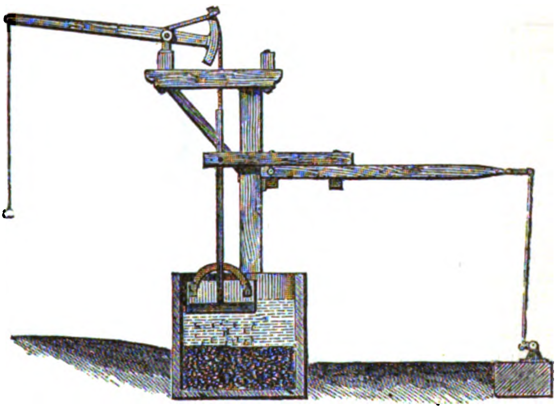


Fig. 136.—Ore-washing apparatus.

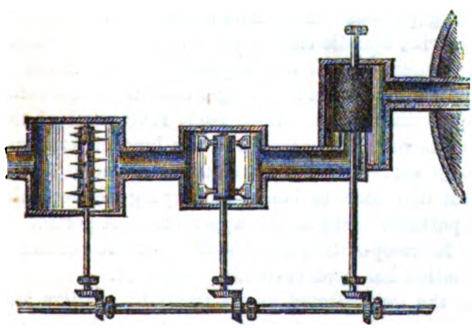


Fig. 137.—Ore-washing apparatus.

The construction of the buddle is illustrated by Fig. 138, which is a vertical section. It consists of an excavation from eighteen to twenty-four feet diameter, and two or three feet deep, with a floor rising eight or nine inches to the centre, where there is fixed a conical wooden block. A vertical spindle carrying a funnel-shaped hopper, with two projecting arms, rests on the centre block, and is driven by bevel gearing at the top. To each of the projecting arms is attached, by cords running over pulleys, a board, fitted on the lower face through its length with a brush. The weight of the board is balanced to an extent by small blocks attached to the suspending cords. On one side of the excavation is a

small sluice-gate, through which the water is permitted to escape as the excavation fills with matter. The ore and water enter through the funnel, and striking against the apex of the conical block, are distributed radially over the bottom. Motion being communicated to the centre spindle, the hanging boards and brushes are drawn lightly over the surface of the accumulating ore. By attention to the balancing weights attached to the cords, the pressure with which the brushes press on the mass, during their passage, may be regulated to the requirements of the ore. The value of the deposit in the excavation is determined in the same manner as with the simplest kind of buddle; namely, the richest portions at the head or centre, near the entrance of the liquid, gradually diminishing in value to the edge of the pit, where a broad ring of "tailings," or worthless matter, is taken out. The central portion is carefully taken out as clean ore, while the portion between this and the tailings is subjected to a repetition of the agitating and buddling process.

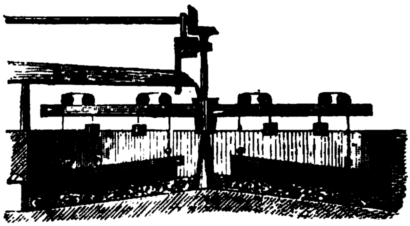


Fig. 138.

The water from the buddle holds in mixture a quantity of fine ore, which separates, to a great extent, by allowing the water to remain for a period in large pits; it is then drained off, and the sediment deposited on the bottom removed to undergo a cleansing process. This may consist of a revolving "trunking" apparatus. A revolving spindle carries two broad paddles; these work in a small cistern, into which the fine ore is placed, and a stream of water enters. In front of the small cistern is a longer cistern, of the same width, but slightly declining to the outlet. With each revolution of the paddles, a small quantity of the mixture passes into the long cistern, and flowing slowly over the smooth surface, the solid matter suspended in the water is again deposited; but this time in bands of varying richness, the heaviest and most valuable particles being at the upper end. A portion of the remainder is placed aside for re-operating on; but the extreme portion is not of much value, if the operation has been carefully conducted.

Mention must be made of the ore rejected as too small by spallers and cobbers; it is picked over, and the richest pieces passed to the best-ore heap. The remainder is subjected to a riddle with inch meshes, and again through one with half-inch meshes. The large from both these processes is picked over, and, along with the small, subjected to dressing operations similar to those already described.

In addition to the returns from the ores obtained, some of the mines yield considerable quantities of precipitated copper from the cupreous waters. The prevailing ore being the sulphuret of iron and copper, a portion of the metal is dissolved by the sulphuric acid, and held in solution. The action of this acid water on the iron-work of the pumps, as well as on the engine-

boilers, is most energetic, destroying annually several thousand pounds' worth of boilers alone. By allowing it to flow into cisterns or hutches to deposit the muddy matters in suspension, and then into other cisterns containing scrap-iron resting on suitable wooden supports, a quantity of impure copper is deposited at the expense of the iron. Theoretically, a ton of iron should be more than sufficient to precipitate a ton of copper; but in practice the consumption varies from four or five to nearly twenty of scrap to one of copper. The cause of the action on iron-work, though explained on chemical grounds, seems, in many instances, to arise from the presence or absence of some alloy with the iron. Steam-boiler plates are frequently attacked, apparently in a very capricious manner; small portions are dissolved, while the adjoining part continues nearly unacted on.

Sale of the Copper Ores.—In the iron manufacture, the mining and raising the ores, fuels, and fluxes, which are usually found in close proximity to each other, and the operations of smelting, refining, and conversion into malleable iron, are generally combined in one firm, whose returns are derived from the sale of the finished iron. Copper-mining is a branch of industry quite distinct from copper-smelting; and though, in a few instances, smelters have a personal interest in mines, as a rule, the mine-proprietor's interest in the ore ceases at the mine. The copper ores having been as completely dressed as local circumstances will allow, they are conveyed to the neighbourhood of Swansea for smelting, where the fuel is obtained at a comparatively cheap rate.

The final operation on the ore at the mine consists in sorting the quantity raised into piles of different degrees of richness, if the quantity is considerable, weighing each lot previous to depositing it on the floor, and appending a wooden ticket of the weight. It is now sold by tender to the highest bidder among the smelters. The value rises and falls according to the price of copper, and according to the percentage of copper in the ore. To ascertain nearly the current value, a portion of the ore well mixed is taken as a fair sample of the contents of the pile, crushed fine in a mortar, and submitted to a crucible assay in a wind-furnace along with the requisite fluxes. The assayer of each smelting establishment is supplied with a portion of the general sample, and the assay is performed for the guidance of his employers. From this assay an approximate estimate is formed of the percentage of metallic copper in the lot for sale, and consequently of the value of the ore with copper at a stated price. Assuming copper to be worth £120 per ton of 20 cwts., and the ore to contain by assay 8 per cent. of metallic copper (an average yield for some British ores), the smelter estimates that it will require 12·5 tons to produce a ton of copper, and accordingly offers at the rate of £9 12*s*. per ton, less the cost of converting the ore into metal, and smelter's profit. This deduction goes under the name of "returning charges," and comprises all expenses which the smelter incurs from securing the ore from the miner to the completion of the smelting process. The sum deducted for ores in Cornwall is £2 15*s*.; for those at Swansea sales, £2 5*s*. per ton. This gives the miner £6 17*s*. per ton for his ore; but, through a long-

established rule, he sells to the smelter 21 cwts. for a ton, giving the latter a bonus of five per cent.; thus reducing the miner's share to £6 10*s*. 6*d*. the legal ton. Under such circumstances, the proportion going to the miner is £81 16*s*. 3*d*., and to the smelter £38 3*s*. 9*d*., for the ton of copper at £120. In reality, however, the smelter's share is much larger, the assay falling considerably under the yield in the large way, as is demonstrated by accurate chemical analysis.

When the produce is large, as in the case of several of the Cuban and Australian ores, a somewhat arbitrary system of fixing the price is adopted. The £2 5*s*. returning charge is augmented to £20 or £25 in very rich ores. For instance, a parcel of Cuban ore at Swansea, of 63 per cent. produce by assay, brings only £63 18*s*., though copper is selling at £126. In this case the miner is paid £100 18*s*. 6*d*., and the smelter receives £23 1*s*. 6*d*., or £14 10*s*. per ton of ore for returning charges. This inequality is met by paying for very poor ores a price greater than their percentage and trade usage seem to warrant. With copper at a similar price, ores containing 5·75 per cent. brought £5 1*s*. per ton of 20 cwts., or £87 15*s*. per ton of copper, leaving £38 5*s*. or £2 4*s*. per ton of ore for returning charges. Thus, whatever be the percentage of copper in the ore, the returning charges are modified so as to give the smelter a sum of nearly £40 for each ton of copper as his share of the proceeds.

The system of submitting the ores for sale by tender, seems equitable, and calculated to give the miner the real value of his ores; but the competition is limited to too small a number completely to ensure this desideratum. The smelting of the ores is performed by about twelve firms; but the control of the trade, the regulation of prices and wages, and the prosperity of the miner generally, are in the hands of three firms, who collectively purchase more than a half of the total quantity of ores sold in Cornwall and Wales; while the purchases of six of the remaining nine firms do not amount to more than one of the larger ones. In consequence of this concentration of the trade in the hands of three private firms, the competition system, so far from affording the miner the value of his ores, is altogether illusory. A consideration of the conflicting interests of miner and smelter is, however, foreign to the objects of this work; although it may be permitted us to remark, that the baneful effects of a system which places such unlimited power in their hands, is only too apparent in the paucity of inventions emanating from the smelting interests.

The rapid increase in the quantity of copper ore mixed in Cornwall and Devon, since the beginning of the last century, is well exemplified in the following abridgment of statistics from the *Mining Journal*:—

Year.	Tons of copper ore.
1732	1,714
1768	23,684
1800	55,981
1820	91,473
1840	147,266
1855	188,696

For 1856, the returns are 209,305 tons of ore for Cornwall and Devon, realizing £1,283,639, or an average price of £6 2*s.* 6*d.* long weight. During the same period, the ore sold in Wales amounted to 46,481 tons, realizing £698,413, or an average price of £15 0*s.* 6*d.* The estimated quantity of fine copper in the 255,786 tons of ore was 19,745 tons.

The ore from the Cornwall district is the produce of more than 140 mines—110 of which raise more than 200 tons annually. One mine produces nearly 30,000 tons; one, 10,000; three, 8000; four over 5000; fifteen over 3000 tons; the remaining eighty-six, smaller quantities. The ores sold at Swansea are composed, the one-half of the produce of Cuban mines, the other half of Spanish, Australian, French, African, Irish, Welsh, and South American mines.

Copper Smelting.—The extraction of copper in the metallic state from its ores, is effected principally in the neighbourhood of Swansea, in South Wales. This locality is admirably adapted for the purpose, on account of the ready accessibility of the port for ships from all quarters; on account of the abundance of coals in the neighbourhood; as well as of all the other materials necessary for the smelting operations. The abundance of coals is of advantage, not merely for saving of cost of fuel at the furnaces, but also on account of the reduced cost of freight of ores from Devon and Cornwall, arising from ships having back-freights ready, for coals to the mines from which the ores were obtained. By far the greater number of the smelting-works in Great Britain are congregated within a few miles of Swansea. The supplies of ores are obtained from Devon, Cornwall, Anglesea, the Isle of Man, Ireland, Jamaica, Cuba, Chili, Peru, New Zealand, the Cape of Good Hope, and Australia.

The greater portion of the ores imported into Swansea are sulphurets of copper, metallic copper, oxides, carbonates, phosphates, silicates, arseniates, associated with minerals of iron, arsenic, antimony, silver, lead, zinc, and tin, as well as with the earthy minerals of lime, magnesia, silica, alumina, baryta, and strontia. With the ores are also required, as fluxes, lime, silica, clay, and fluor spar. Most of these are obtained from the immediate neighbourhood, but the fluor spar is procured principally from the Tamar Mines.

Successful economical management of smelting operations is dependent principally on the due assortment of the ores for the various operations involved in the preparation of them, and for the final production of metallic copper. These operations are ten in number; and for them the crude ores are assorted into five classes, viz.:—

1st. Such ores as contain three to sixteen per cent. of copper combined with sulphur, and with iron also mineralized with sulphur, forming iron pyrites and arsenic associated with quartz and other siliceous and earthy minerals.

2nd. Ores of similar constitution, but containing from fifteen to twenty-five per cent. of copper.

3rd. Sulphurets of copper, with less of the sulphurets of iron, containing fifteen to twenty per cent. of copper, a portion of which is in the state of oxide, principally associated with siliceous minerals.

4th. Principally oxides and carbonates of copper with some of the sulphurets of copper, containing from twenty to thirty per cent. of pure metal; the associate minerals being principally siliceous.

5th. Rich oxides of copper, free from sulphur and arsenic, or other metals which can have an injurious effect on the metal, obtainable from these ores, which contain from sixty to eighty per cent. of copper; the accompanying minerals being chiefly quartzose. They are obtained principally from Australia and Chili.

The ten operations involved in the treatment of these ores are as follow:—

1. Roasting or calcining ores of the first and second class, for the separation of such of the constituents as are capable of being volatilized by the action of heat—such as sulphur, arsenic, zinc, antimony, &c.
2. Fusion of the calcined product of the first operation with minerals of the second class not previously calcined. This operation is termed, melting for coarse metal.
3. Roasting of coarse metal.
4. Melting for white metal. In this operation, the coarse metal is fused together with ores of the fourth class.
5. Melting for blue metal. The calcined coarse metal is fused with roasted ores rather rich in copper.
6. Remelting of slags from Operations 4, 7, and 8.
7. Roasting of white metal for the production of white metal of superior quality.
8. Roasting for regule.
9. Preparation of crude copper by roasting and fusion of regule.
10. Refining and toughening of crude copper, producing fine metal.

For the purpose of showing clearly the character and objects of these ten operations, considered in detail, the following statement of analyses of the constitution of the more common ores is necessary:—

Copper	Antimony	Sulphur
Iron	Zinc	Alumina
Arsenic	Lead	Silica

The separation of the copper in a state of purity is, of course, the object of all the operations just enumerated. As a simple chemical question, it can be comparatively easily done on the scale of ordinary laboratory operations; but for practical purposes, the same means cannot be adopted, principally on account of the too great cost of the agents required, but also because of the too great nicety of process for the ordinary labour employed in such extensive operations.

The First Operation has for its object the separation of all the substances capable of being volatilized by heat. This is effected by exposing the ore, in a roughly-pulverized condition, to the conjoint action of heat and of the atmosphere in a reverberatory furnace, shown in plan and section in Figs. 139 and 140.

The furnace consists essentially of a fire-place for the production of the heat, and of the sole, or laboratory, on which the crude ore is subjected to

its action. They are divided from each other by the bridge, which is so constructed as to admit heated air to the gases produced in the fire-place, which, for the regular distribution of the heat over the whole of the sole of the furnace, requires to be ignited, not within the fire-place, but at the back of the bridge, so entering into full combustion, and producing streams of flame over the whole surface of the sole. As the production of an oxidating flame should be the object in this furnace, the proper arrangement of the bridge for controlling the admission of air is of the greatest importance. The regular distribution of the heat over the whole of the furnace is effected by having the arch three feet high over the bridge, gradually diminishing to one foot over the back bridge. The sole, or laboratory of the furnace, is usually from sixteen to twenty-four feet square, having two doors on each side, through which the workman rakes over, or rabbles, the charge of ore at intervals of one and a half to two hours, so as to expose fresh surfaces to the action of the heated air passing over it. The charge is introduced through hoppers fixed in the arch of the furnace; and when the calcination is completed, it is drawn through holes in the bed or sole of the furnace into an arched recess below. The bed of the furnace may, with advantage, be extended to sixty feet by sixteen feet, being divided into four different parts, each three inches higher than the other. The consumption of coals in this operation need be but very small, as when the ore is first introduced, the assistance of heated air alone is sufficient to maintain the combustion of the sulphur of the ore, the heat from which causes the evolution of arsenious acid from the arsenic. The gradual increase of heat in the charge is very necessary to be provided for,

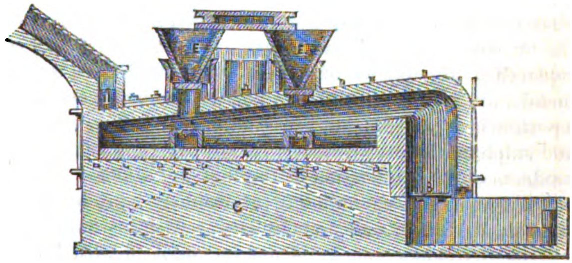


Fig. 139.

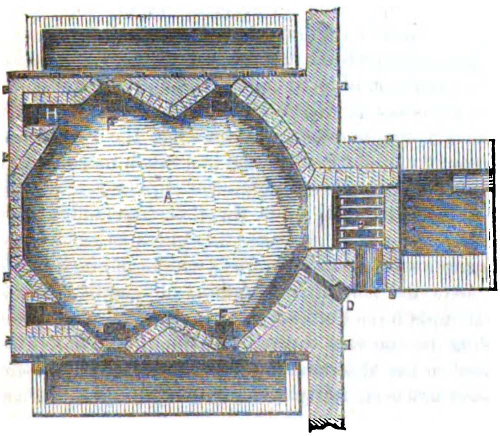


Fig. 140.

as with too much heat the charge, while still holding much sulphur and arsenic in combination, is very liable to be fused; and in this condition the evolution of the sulphur and arsenic is very much impeded, as is also the oxidation of the other metals present. When the charge is drawn, it still contains some sulphurets and some sulphates; most of the sulphur, arsenic, antimony, and zinc, will have been evolved; the copper and the iron not remaining in combination with sulphur, will have been converted into oxides; and the siliceous or earthy matters will remain unchanged. Unless a very large quantity of arsenic and other volatile metals shall have been driven off, the charge, when drawn, will not differ much in weight from the charge put into the furnace, as the sulphur evolved will have been, to a considerable extent, replaced by the oxygen of the air, which will have combined with the other metals, producing oxides. The volatile products pass off into the flues, where a portion is deposited; but the remainder, consisting principally of sulphurous and sulphuric acids, together with the carbonic acid, water, and nitrogen, the products of the combustion of the fuel, are diffused from the top of the chimney through the surrounding atmosphere; producing such effects on the adjacent vegetation, as prevent strangers from agreeing with the belief of natives, that copper-smoke is not inconsistent with human longevity. The frosted appearance of the glass in the windows of houses accessible to copper smoke, indicates the presence also of fluoric acid in the smoke, which, acting on the silica of the glass, affects its transparency. It has been estimated that in South Wales alone about 50,000 tons of sulphur are annually dissipated in the atmosphere, in the form of sulphurous and sulphuric acids.

By the adoption of means to be hereafter noticed, a very large proportion of this sulphur might be rendered available, in the form of sulphuric acid, for the numerous manufacturing purposes for which this important chemical agent is required; and thus, while a valuable product is obtained, the deleterious effects on the surrounding country might be confined to a much more limited extent. In certain conditions of the atmosphere, the copper smoke falls heavily over the neighbourhood, extending for three or four miles from the works; and the fog produced by it is so dense as almost to render the roads impassable. In order to avoid the effects of this smoke in one place, a chimney has been built up over the side of a mountain, sufficiently large to drive a coach through. Attempts have been made to condense it completely with the aid of water falling in showers through the flues; but as yet the coke towers, successfully used in the soda manufactories for the condensation of muriatic acid vapour, have not been fairly tried, although equal success might be anticipated.

The reverberatory furnace may be built of copper slag-blocks, cast in moulds eighteen inches by nine inches, faced internally with fire-brick, and externally with fire-brick or common brick; the whole laid with fire-clay; the fronts and sides covered with plates of cast-iron, suitably bound together with cast-iron studs and wrought-iron braces. The products of combustion pass off over the back bridge into a descending-flue, on into underground flues, communicating with the main-shaft or chimney.

A still further economy of fuel than that already indicated may be effected by constructing the back beds of the furnace of plates of cast-iron, causing the heated air and gases to circulate in flues below the plates before finally passing away through the descending-flue. The cast-iron soles are more durable than the fire-brick usually employed; and the labour for rabbling or turning over the charges may be applied with much greater effect. Lengthened experience has shown that the cast-iron plates are not affected by the united action of heat and sulphur, as might have been anticipated. On this head, see further the article on *Tin Smelting*.

Second Operation.—The reverberatory furnace employed in this operation is about one-third of the capacity of that employed for calcining the raw ore, supposing it to be a single furnace. Its construction is shown in Figs. 141 and 142. It is constructed also of the same materials; but as a very much greater heat is produced within it, much more care is necessary in its construction. It is charged through the hopper with about 20 cwt. of material, consisting of calcined ore from the first operation, a small proportion of crude ore, a small quantity of fluor spar as a flux, some of the scoria of the same operation, and fusible scoria from the fourth, fifth, and seventh operations. The ore and flux having been introduced through the hopper, the workman rapidly spreads the charge over the bed of the furnace, and then introduces the scoria, evenly distributing it over the surface of the ore. The furnace door is carefully closed up, and for three and a half hours the fire is steadily raised, the charge being left undisturbed. Within half an hour after the closing of the furnace, the fusion of the scoria commences; it flows down, and carries the heat rapidly through the charge, which immediately begins to give off sulphurous and other gases, causing an ebullition of the liquid scoria; a rapid reaction is produced between the earthy and metallic constituents, the iron and silica entering into combination, and with the assistance of lime of the fluor spar, forming with the alumina present a very liquid scoria, through which the heavier fused sulphuret of copper falls to the bottom, where, from the peculiar hollow form of the bed, it is all brought together. At the end of three and a half hours the furnace door is opened, the furnace-

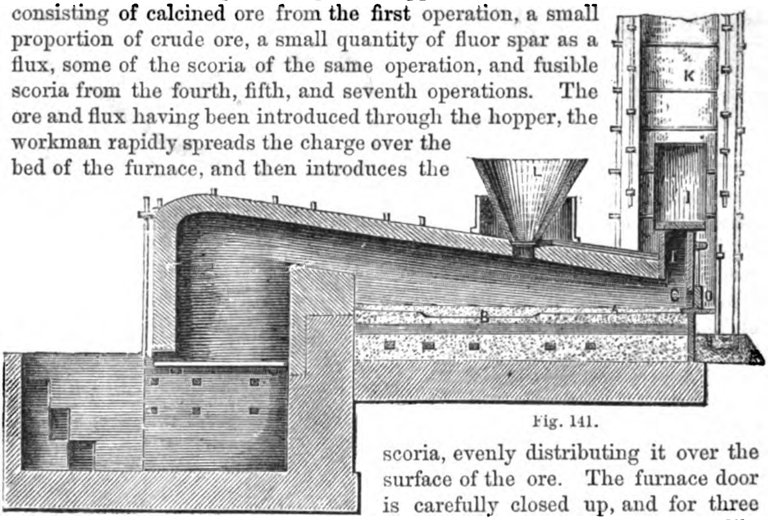


Fig. 141.

man clears off with his rake the unfused portions remaining around the sides of the furnace, turning them into the liquid mass, which acts rapidly on them, reducing them also to the liquid condition. The door is again closed and the fire urged on to greater intensity. At the end of another quarter of an hour the furnace is carefully tapped at the bottom of the basin, so as to allow the liquid mass to run off into an iron cylinder immersed in water. In this manner the mass is granulated and brought into a suitable form for the next operation. While the liquid mass is still running off, the furnace door

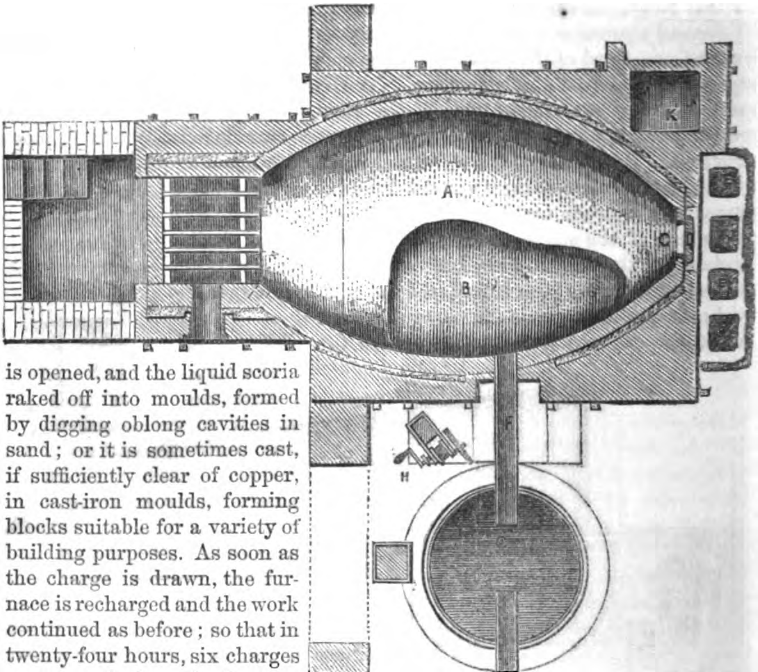


Fig. 142.

is opened, and the liquid scoria raked off into moulds, formed by digging oblong cavities in sand; or it is sometimes cast, if sufficiently clear of copper, in cast-iron moulds, forming blocks suitable for a variety of building purposes. As soon as the charge is drawn, the furnace is recharged and the work continued as before; so that in twenty-four hours, six charges are passed through the furnace. It is evident that ores containing fluor spar are more valuable than those which contain silica alone; as not only do they not contain so much silica to be removed, but they also provide a flux for other ores which are siliceous. It is evident, therefore, that much judgment is requisite for the due assortment of the ores for this process. The object of this operation is to separate the metallic from the earthy matters; and so we find that the products consist of about one-third coarse metal, composed principally of sulphuret of copper and sulphuret of iron in nearly equal quantities, and of two-thirds scoria, containing iron, silica, alumina, lime, and fluoride of calcium or fluor spar, all fused together into one homogeneous substance. The cast blocks of scoria are carefully examined when

cold, to determine whether any of the coarse metal be left in it. The peculiar colour and form of fracture of the brick gives a very nice indication of the quantity of copper, down to so minute a proportion as $\frac{1}{1000}$th to $\frac{2}{1000}$th part. The portions containing matt or coarse metal, usually amounting to about seven per cent., are separated, and reserved for a new charge for the same operation, and the remainder is carried off to the waste heap.

The fluor-spar employed as flux is peculiarly valuable, both as a mechanical and chemical agent. Under the influence of heat it fuses on coming into contact with silica, the calcium obtaining oxygen; the silicon and fluorine set free from the calcium combine; and, as a gaseous product, in passing off, produce an agitation of the fluid mass, which is highly conducive to the perfect reaction of the various constituents on each other. The lime thus set free immediately enters into combination with another portion of silica, forming with the other earthy matters present, through the assistance of a portion of the iron, a very fluid slag; the cylinder containing the granulated matt is lifted out of the water by a crane fixed to the furnace, and is removed in wheel-barrows or waggons to the furnace employed for the next operation.

Third Operation.—For this process, precisely the same sort of furnace is used as for the first operation. It is charged in the same manner, from the hoppers on the roof of the furnace, with the product of the second operation, which may be regarded as copper pyrites free from gangue or earthy matrix, and containing about thirty-three per cent. of copper. The heat employed in this operation is much greater than in the first, as the constituents of the charge are not nearly so fusible. The object is to drive off as much as possible of the remaining sulphur. The fire requires to be managed so as to produce an oxidating flame; that is, flame greatly supercharged with atmospheric air, undecomposed, but highly heated by the fuel. This necessity arises from the fact that heat alone is not sufficient for the expulsion of the sulphur; but when heated oxygen is brought into contact with the materials of the charge, it partly combines with the sulphur, forming sulphurous acid, the detachment of the sulphur from the iron and the copper being facilitated by the intervention of other quantities of oxygen, entering into combination with the metallic bases forming oxides, principally of copper and of iron. The alternate employment of an oxidating or clear flame, and of a reducing or smoky flame, is advantageous, as, under the influence of the former, sulphates are sometimes formed. The residuary sulphurets, with the sulphates, are more rapidly decomposed by their reaction on each other, under the influence of the reducing-flame, than they would otherwise have been, the sulphur of the sulphuret combining with a portion of the oxygen of the sulphuric acid of the sulphate, its base obtaining its oxygen from the same source, the sulphurous acid passing off. The charge begins to throw off vapours as soon as it gets red-hot throughout, or in about two hours after it is put into the furnace. It is then well raked over, to cause every portion in succession to be exposed to the action of the heated air passing through the furnace. The raking or rabbling is repeated every two hours, the heat being

maintained as high as possible, short of causing the charge to fuse. At the end of twenty-four hours the heat will be equal to about cherry-red; and at the end of thirty-six hours at a bright red, by which time the calcination should be complete and the charge ready to draw. The product of this operation is "coarse metal," which should be as nearly as possible pure oxides of iron and copper. It is much altered in colour, and reduced to a coarse granular condition much smaller than before. If well done, the fragments are of a deep black colour, with some indications of incipient fusion on the grains. Much more coals are consumed in this than in the first operation, but not so much as in the second.

Fourth Operation.—The furnace is of the same form as that employed in the second operation, excepting that there is no basin-formed recess in the bed, but a gradual slope of it, so as to discharge the whole of the fused mass readily from a hole in one of the long sides. The charge is composed of coarse metal, the product of the third operation, mixed with minerals of the fourth class, such as sulphuret of copper free from admixture of iron pyrites, or the carbonate or oxide of copper and copper slag from the ninth and tenth operations; together with copper scales from the rolling of copper or other copper wastes, such as are produced in the working of copper into utensils for machinery. The object of this operation is to separate the iron by combining it with silica, forming a silicate of iron, leaving the copper in combination with sulphur in such proportion as will form a sulphuret of copper. With such a variety of materials to work on, a superior class of workmen is required for conducting this operation; for they are not limited by such rigid rules as in the previous operations, being allowed to operate on successive charges, as may be indicated by the results of previous workings The materials for a charge amount to about thirty cwt. The charge is introduced through the side door, and is spread over the bed with an iron slicer, shaped somewhat like an oar or paddle. The door is carefully closed, and the heat raised as rapidly as possible. During the first two hours a calcination goes on, attended with the evolution of some sulphurous acid, and an incipient fusion takes place as the heat increases. The charge flows down, until, at the end of the third hour, the fusion is complete, the scoria is very liquid, and remains quiet in the furnace. Between the fourth and fifth hour the charge is well and rapidly stirred; the unfused portions of the charge adhering to the sides are turned into the liquid mass; and then the furnace is again closed, and the heat urged on until the whole of the interior of the furnace is raised to a dazzling whiteness. At the end of six hours the furnace is tapped, the matt is run into water, and thereby granulated, the very liquid scoria being conducted through another channel, after the matt has been run off, into sand moulds. The scoria is sorted into two qualities: the first run off, having been in contact with the matt, retains three to five per cent. of copper, and is reserved for the sixth operation; the last portion run off contains much less copper, and is used as a flux in the second operation. The matt, consisting principally of sulphuret of copper, still retains four to eight per cent. of sulphuret of iron, and contains seventy to seventy-five per cent. of copper. This

matt is termed "white metal." In its purest form it is of a grayish-white colour, of a granulated porous texture, sometimes of a bluish-gray colour, with a specific gravity of 5·2 to 5·7. It is reserved for the ninth operation. The working somewhat resembles the second operation; but as the heat required is much greater, more fuel is consumed. Twenty-two charges are worked through the furnace in a week.

Fifth Operation.—The furnace employed precisely resembles that used for the fourth operation; and, indeed, the two operations much resemble each other. The charge on the present occasion consists of materials containing fewer metallic oxides than those of the last operation, but having more metallic sulphurets. Excepting that some of the products of the present are brought into other operations, together with the products of previous processes, it would hardly require a separate description, but would rather be an equivalent for the fourth operation; its principal object being, by the better selection of ores containing a less variety of substances, to produce from them a "blue metal," from which blue copper may with less difficulty be elaborated. The white metal, the product of the fourth operation, does not contain any metallic copper; but the blue metal is characterised by the presence of metallic copper, diffused throughout the mass in exceedingly minute particles.

About the same quantity of fuel is used as in the fourth operation, the reactions that take place in the furnace are similar, and the products are disposed of in much the same manner. The matt contains from seventy to seventy-five per cent. of copper.

Sixth Operation.—The object of this operation is, by the combined action of the various constituents of the slags from the sixth, seventh, and eighth operations on each other, to cause the production of a matt in which the copper in these slags shall be brought together. A small quantity of copper pyrites, free from other combinations than siliceous matter in large proportions, is mixed with the slags. After the mass is fused, a small quantity of coal or other carbonaceous matter is mixed with the charge, which reacts on the oxide of copper, decomposing it, and producing a metallic copper, which alloys with any tin, nickel, cobalt, or arsenic present; and falling to the bottom under the matt, does great service by eliminating these metals from the superincumbent matt. The same sort of furnace is used as in the last operation; but the materials of the charge, instead of being supplied to the furnace through a hopper in the roof, are introduced through the ordinary working-door, and another door placed more nearly in the corner of the furnace; the fused charge is drawn off from the side opposite to the working-door. Each charge, of about two tons in weight, takes about six hours for working off. The products are, white metal for the sixth operation; red metal, for the same operation; the bottoms, or alloy of metals, divided into tin alloy and copper alloy, for the ninth operation; scoria, for returning to the fourth operation; and slag, to be rejected to the extent of ninety per cent.: so that it will be seen that this operation is very efficient in the reduction of bulk of useless materials.

The Seventh Operation is carried on in a furnace resembling the one used in the sixth. The charge consists of about two tons of blue metal only, without any other flux than the sand adhering to its surface from the moulds in which it was cast. As the operation is twofold—first, for calcination or oxidation, and then for fusion—the bridge is provided with an air-passage, similar to that employed in the calcining furnace for the first operation. The charge is put into the furnace in large masses, and the heat is slowly raised upon it, so as to oxidize as completely as possible all the metal present. When the whole mass is fused, the sulphuret of iron having been converted into oxide of iron and sulphurous acid, the silica reacts on the iron, and is converted into a fusible silicate; some oxide of copper is also scorified, but the matt or white metal produced is much improved in quality, and rendered fit for the eighth operation. The operation requires about twelve hours for its completion; and but little alteration has taken place between the weights of the charge introduced and of the products obtained, none of the latter being finished with, but having to be redistributed to the furnaces for the second, fourth, and sixth operations.

The Eighth Operation is conducted in a furnace precisely similar in every respect to the furnace employed for the seventh operation. The materials constituting the charge are white metal, produced from the sixth and seventh operations, together with the red metal from the sixth operation, without any other flux than the sand adhering to the blocks from the moulds in which they were cast. The operation lasts about four hours, the weight of the charge being about one ton and a half. At first, as in the last operation, the effect is that of oxidation; but as the fusion proceeds, the oxide of copper which has been produced, coming into contact with sulphuret of copper, a reaction takes place, sulphurous acid is evolved, and metallic copper precipitated, or a subsulphuret of copper is produced. The products are three, all of which have to be reworked. They are—1st, a regulus, consisting of copper 81, iron ·2, sulphur nearly 2 per cent.; 2nd, a slag, consisting almost entirely of silica, and oxides of iron and copper, with about ten per cent. of copper mechanically mixed; 3rd, copper bottoms, or alloys of copper with other metals. These are reserved for the ninth operation; and some of the slag is returned to the furnace for the fourth operation.

Ninth Operation.—The same sort of furnace is used as in the last operation. The charge, amounting to from 2½ to 3¼ tons, consists of white metal from the fourth operation, regulus from the eighth operation, copper bottoms from the sixth and eighth, and a small proportion of rich oxide, or carbonate ores, associated with quartzose matrix or gangue. No other flux is added than the silica of the rich ore. The heat of the furnace is at first regulated for the calcining of the charge, and is gradually raised until the whole mass is perfectly fused. The object of the calcination is to promote the oxidation of the metals and of the sulphur: the sulphur, being converted into sulphurous acid, passes off, together with arsenic if it be present. By fusion of the oxidated matters, oxide of copper is brought into contact with sulphuret of copper, oxygen leaving the copper and combining with the sulphur; the two

in combination assuming the gaseous form, produce a most desirable agitation of the constituents of the charge, whereby in succession matters having chemical reactions on each other are brought into contact, and the desired changes are effected. As only a limited supply of oxygen is contained within the charge, and this is soon exhausted by the reactions that take place within the fluid mass, it becomes necessary to obtain a fresh supply. In the fused state the charge presents but a very small amount of surface for the reaction of the heated air passing through the furnace. The production of the necessary surface for the further oxidation is effected in a simple but ingenious manner. The furnace is allowed to cool, by opening the doors, down to a dull red heat; in so doing, the crust formed over the surface of the fluid mass is broken up by the sulphurous acid passing off. As the charge throughout becomes more and more pasty, it is rendered more porous by the gas evolved, through the agency of the oxygen of the heated air coming into contact with it, which, at the same time that it is expelling the sulphur, is also being stored up within the mass by the combining action of the copper, iron, and other metals present. At the end of about twelve hours the charge is so far cooled that the disengagement of the gas ceases. The doors are again closed, the heat is gradually raised during the next six hours, fusion slowly takes place, calcination at first going on; and after the mass has again become fluid, the mutual reaction of the oxides and sulphurets, as before indicated, again take place. The heat is then urged on to the utmost; the silica and iron entering into combination, produce a slag, together with the remaining small proportions of antimony, arsenic, &c., through which the fused metallic copper finds its way to the sole of the furnace.

At the end of twenty-four hours the charge is drawn, the slag being skimmed off, and the metal cast into blocks about three feet long and eighteen inches wide. This product is known as blistered copper, and amounts to about sixty per cent. of the weight of the charge put into the furnace. The residuary slag, which not unfrequently contains fifteen to twenty per cent. of copper, is sorted and returned to the furnaces for the fourth and sixth operations. The blistered copper is so called because the surface of the ingots is covered with blisters; the interior is full of cavities, the fractured surface, when fresh, being of a deep-red colour.

Tenth Operation.—Refining the coarse metal produced in the last process is conducted in a similar furnace, having a larger fire-place and the roof somewhat higher above the sole, so as to allow of the piling of the charge of ingots, seven to ten tons weight, on and over each other. These require to be so arranged as to allow of a free draught through the furnace, but with a regular equable distribution of heat. During the first eighteen hours, the workman has only to maintain the fire so as steadily to raise the heat of the furnace.

A calcination and an oxidation at first goes on during the slow fusion, as in the last operation, more sulphur being evolved; and when the fusion is complete, the silica adhering to the ingots fuses, together with some of the oxide of copper, at the same time laying hold of most, if not all, of the other

metallic oxides remaining in combination. At the end of twenty-two hours, the scoria thus produced is raked off, leaving the surface of the metal as clean as possible. A few shovelfuls of powdered wood-charcoal, or finely-pulverized anthracite of the best quality, are thrown on the surface of the charge, and rapidly spread over it. A short time after this, a pole of green wood is plunged into the fused metal; a violent ebullition takes place, causing a more intimate mixture of the copper and the charcoal; and probably the steam and gaseous products evolved, assist in the elimination of any traces of sulphur left within the metal. This action with the pole, termed "poling," is maintained for about twenty minutes. The superintendent then takes out a small sample of the metal in a ladle; when cooled, he examines it by cutting the ingot half-way through with a steel chisel; then bending it in a vice back to a double, by which means the fibre of the metal is developed, the colour and flexibility is ascertained, and it is determined whether the refining is complete.

If the poling has not been continued long enough, the metal will be brittle; so also will it be if the poling has been continued too long. In the latter case the metal is restored, but with some difficulty, by clearing the surface of the metal, and allowing heated air to pass over it, apparently for the purpose of decarbonizing the metal. When the metal has been over-poled, it becomes exceedingly bright and brilliantly clear, so that the roof of the furnace may be seen reflected on its surface. Before poling, the copper is in a peculiar condition, termed the *dry state*, probably consisting of much oxide of copper and oxygen in contact with the metal. In this condition it has a very strong action on the iron tools used in working the charge. The desired point having been attained by the refiner, the charge is again skimmed, a smoky flame is produced in the furnace to prevent oxidation, and the metal is taken out in ladles covered with a wash of fire-clay, and cast into moulds, varying according to the quality or form required for the market. Various qualities of copper are met with in the market, varying from £5 to £6 per ton in price; they are known as "best selected," "tough copper," and "tile copper." These vary in quality, according to the choice of products for the tenth or refining operation.

The various operations here described have been modified in different smelting establishments, but the principles involved are substantially the same. At first sight, they appear to be exceedingly complicated and unnecessarily extended in number; but, on closer investigation, it will be found that, with the aid of the closest application of scientific principles, a more perfect system of operations could scarcely be devised. During the last twenty years, a great number of patents have been taken out for improvements in the smelting of copper ores; but, either from want of merit or from want of proper trial, very few have been permanently adopted, and but very slight improvements have been generally introduced throughout the smelting establishments of Wales.

In order to the perfect development of the present system of working, the closest application of scientific principles and of chemical knowledge is abso-

lutely necessary, although very good results have been obtained, much better than could have been anticipated, from simply empirical or rule of thumb working. For example, a perfect analysis of the ores purchased would indicate with precision the quality and quantity of the various ores that should be associated for the production of the best effects of calcination; it would also serve to show the real value of the different ores—not simply on account of the proportion of copper contained in them, but also on account of the comparative value of the associated minerals, as fluxes, &c. The knowledge of the true character of each of the operations employed would give the power of regulating, with precision, the results to be obtained. Empirical knowledge is sufficient for the production of tolerable results, as long as all things go smoothly; but more than this is necessary to set right again processes which have gone wrong. It is when the experience gained by prolonged acquaintance with practical operations on the large scale, is aided by the scientific knowledge gained by the careful investigation of the character of the phenomena observable, and of the principles involved in their production, that such a command over circumstances is obtained as will ensure the production of results at will.

In the Swansea district there are nearly six hundred furnaces employed, consuming about 500,000 tons of coal per annum, employing, exclusive of colliers, about four thousand persons, who receive nearly £4000 per week as wages. About twenty tons of coal are consumed, on an average, for the production of one ton of copper. Copper is brought into the market in a variety of forms, such as bean-shot or feathered-shot, intended for the manufacture of brass. The former of these is produced by pouring the melted copper through ladles, filled with holes, into hot water, for the production of bean-shot, or cold water for the manufacture of feathered-shot. It is cast into slabs when required for hammering out into shape for large utensils, such, for instance, as vacuum pans for sugar-refining purposes; in which case a small slab, with the aid of a Nasmyth's steam-hammer, is hammered out into the form of a hemisphere, with a rim eight to nine feet in diameter out to out, and four feet deep. It is also cast into ingots of various sizes. One form of ingot is only six ounces in weight, and about eight inches long. It is exported to the East Indies as Chinese or Japan copper. These ingots are of a fine red colour, produced by throwing them while hot into cold water. The method of producing this colour was for a long time kept secret by a single firm, who had discovered it, and had thereby succeeded in producing an article which they successfully brought into competition with the Chinese or Japanese article, which had previously completely monopolized the market.

The slabs are also, some portion of them, before being sent away from the smelting works, converted into sheets of varying thickness, by rolling between smooth iron rollers, each about three feet eight inches long, and fifteen inches in diameter. The ingots of copper to be operated upon are heated in a reverberatory furnace, and are then passed through the rollers, returned over them, and passed through again and again, until by cooling and hardening they become so brittle that they require to be annealed by reheating in the furnace.

The rollers are gradually brought closer together by tightening screws bearing on the plummer-blocks, carrying the shaft of one of the rollers. The repeated re-heatings of the sheet produce a coating of oxide, which is removed by steeping for a few days in urine; it is then put again into the furnace, the ammonia attached to the surface is driven off, and the sheet being plunged while hot into cold water, the cupric oxide formed scales off; leaving the metallic surface bare. After passing the sheet, when cold, through the rollers, to produce a smooth surface, it is cut down to the proper size and packed for the market. Very large quantities of sheet-copper have been used for sheathing ships; but it is now superseded, to a great extent, by the introduction of a sort of brass, known as Muntz's yellow metal, as well as by sheet zinc.

The principal places of export are London, Liverpool, and Swansea. The principal places where it is manufactured are Birmingham, Sheffield, London, and Bristol.

Improved Processes.—It has been before observed that the operations, as described, are modified in various smelting establishments to meet peculiar circumstances; but it is surprising how long any improvement in the system of operations takes to obtain extensive adoption. One of these improvements consists in the calcination of copper ores, containing much iron pyrites, in a kiln, instead of a reverberatory furnace, without the assistance of any other combustible matter than the constituent sulphur of the pyrites. The kiln is so arranged that, as in a lime-kiln, the matter to be operated upon is supplied at the top and withdrawn from the bottom. The sulphur, by burning, is converted into sulphurous acid; which meeting with the nitrous acid vapours evolved from a charge of nitrate of soda undergoing decomposition from the action of sulphuric acid in a cast-iron nitre pot placed in the flue leading to an ordinary sulphuric acid chamber,—is thereby converted into that extremely useful material, sulphuric acid, which is collected in the chamber, and may thence be obtained for conversion into a suitable form for the numerous purposes for which it is so indispensably necessary. This acid may be employed for the manufacture of superphosphate of lime, as a manure for enriching the soil, instead of being rendered worse than useless, by the ordinary careless way of working, by poisoning the air. If only a small quantity of arsenic be present, the sulphuric acid produced may be purified by a subsequent operation, and rendered fit for common purposes. If the copper ore contain large quantities of arsenic and but little sulphur, it may be calcined advantageously in a similar kiln; but instead of using a lead chamber, the fumes of arsenious acid or white arsenic should be conducted into horizontal chambered flues, made sufficiently large and of such a length that, by cooling, the vapours may be condensed in the form of white powder, and collected for sale to the arsenic refiner. If the ore do not contain sufficient combustible matter to maintain the heat long enough, a small quantity of culm, or anthracite coal, may be advantageously mixed with the ore in charging the furnace, precisely in the same manner as in working lime-kilns. The process for separating the sulphur in the manner above described, was patented in the year 1847, by Birkmyre; but it had been in use nearly as far back as

1840, when this method was introduced for obtaining sulphur from mundics, or iron pyrites, by the soda manufacturers, in consequence of the attempted monopoly of the sulphur trade by the Sicilian monarch. This circumstance gave rise to many attempts to improve the produce of the great variety of metalliferous minerals obtainable in various parts of the United Kingdom.

Amongst others we may notice the patent obtained by W. Longmaid, bearing date October 20, 1842. Its object was to render sulphur ores, including poor copper ores containing much sulphur, available for the purposes for which sulphur was commonly employed. It was found that a large proportion of the ores containing sufficient sulphur, sufficiently free from arsenic to allow of their being employed for the manufacture of sulphuric acid by burning in the kiln, as already described, would be too small to be available for this mode of treatment. In Longmaid's process this difficulty has been overcome; and, at the same time, the necessity for avoiding the use of ores containing much arsenic was evaded. The process consisted in grinding the ores to a coarse powder, and mixing with them a proportion of common salt, or chloride of sodium, having such relation to the sulphur present in the ore, that more than sufficient sulphuric acid necessary for the decomposition of the salt should be obtainable therefrom. The mixture is put upon the back of one of four beds of a reverberatory furnace, sixty feet in length. A very moderate heat reaching the mixture from the fire-place is sufficient to cause the combustion of the sulphur of the ore in contact with the salt: the greater portion of the sulphurous acid produced is converted into sulphuric acid, the sodium of the salt obtaining oxygen from the iron contemporaneously oxidized with the sulphur. The chlorine, set free from the sodium, enters at once into combination with the iron, producing the chloride of iron; and the same action takes place between the salt and the sulphuret of copper. As the heat is increased, by advancing the charge, at the end of twenty-four hours, on to the next bed, a large proportion of the chloride of iron is volatilized, and passes away into the flues with the smoke of the fire; another portion of the chloride of iron, under the influence of the heated oxygen of the air passing through the furnace, is decomposed, the iron being converted into the state of peroxide in a very finely-divided state, with the evolution of gaseous chlorine, the chloride of copper remaining unaffected. By continuous exposure to heat on the different beds of the furnace for from seventy-two to ninety-six hours, with a very small expenditure of fuel and of labour, the whole of the sulphurets present will have been decomposed, and the original charge of chloride of sodium and of sulphur ores will have been converted into a product called sulphate ash, which, by lixiviation in water, is separable into a solution of sulphate of soda, chloride of copper, and chloride of silver, if any of that metal should have been present in the raw ore (and nearly all copper ores do contain it), and insoluble peroxide of iron, which, by levigation, may be perfectly separated from the sandy siliceous constituents of the ore employed. The copper is precipitated from solution either in the state of oxide by soda or lime, or in the metallic state by the employment of metallic iron.

This process has been advantageously employed at St. Helen's, Lancashire, for the manufacture of sulphate of soda, and the extraction of copper and silver, for many years; but as yet it has not been used on the large scale, for operating on the richer sulphurous copper ores. This process has been but feebly worked; but, with energetic management, as a process for smelting copper, the very best results may fairly be anticipated from it. The peroxide of iron is obtained in such a very finely-divided condition, that it is used in the manufacture of the most valuable paint for covering iron, especially if it be exposed to the action of salt-water, as with the bottoms of iron ships. The chlorine products evolved in the course of calcination are so easily condensed, that, with moderately long horizontal flues intervening between the furnace and the chimney, no condenser for the fumes is required, as in the ordinary process of manufacture of salt-cake or sulphate of soda from common salt and liquid sulphuric acid.

The precipitated copper is found associated with the silver originally contained in the raw ore: the separation of the two metals is effected by dissolving the precipitate in sulphuric acid, for the manufacture of sulphate of copper, to be evaporated and crystallized for the production of blue vitriol, which is largely employed for agricultural purposes in pickling wheat, for dyeing, and for a great variety of other chemical purposes. By this process, silver can be obtained from ores containing so small a quantity as one and a half to three ounces per ton, such as could not be economically extracted by any other process. Very small quantities of tin ore are very generally found in most of the copper ores. It may be very easily extracted from the coarse residuary matters found after the separation of all the soluble constituents of the sulphate ash, and of the light peroxide of iron. No other process will compare with this for efficiency in resolving *all* the constituents of sulphur copper ores into valuable useful products.

A. Parkes, in a patent sealed June 11th, 1850, describes a circular reverberatory furnace, with two or more beds or soles over each other, with a central shaft carrying arms holding rakes, which, revolving, serve to turn over or rabble the charge of ore, and gradually transfer it from the top bed, on to which the ore is fed by a hopper, to the next one below; and so on, until the charge, as the calcination is completed, is turned out of the furnace. A much better plan, obviating the manifest difficulty of maintaining the shaft and arms in repair, is to adopt Brunton's calciner, which is a circular reverberatory furnace of only one bed or sole, which is supported on a perpendicular shaft. A rack-work on the under edge of the sole affords the means of revolving the table by the motion of a cog-wheel working in it, driven by machinery of very small power. This calciner was invented for the roasting of tin ores, and has been almost exclusively applied to that purpose, for which it has answered very well; and it would, doubtless, be equally valuable for the calcination of copper and of other ores.

M. Tripier obtained a patent in France, October 10, 1844, which appears to have been copied by A. Trueman in a patent sealed October 7, 1852, wherein it is proposed to treat the ores of copper containing oxides and car-

bonates alone without sulphurets, or sulphurets converted into oxides by roasting, with muriatic or sulphuric acid, precipitating the copper thus taken into solution with muriate of lime and milk of lime. The difficulty of obtaining suitable vessels to withstand the action of the acids is too great to allow of this plan being carried out on the large scale; the same objection is applicable to the various devices patented for the precipitation of copper in solution by galvanic agencies, such as Napier's patent, bearing date of sealing March 2nd, 1847; A. Wall, December 18th, 1844; A. Crosse, August 26th, 1852; and W. H. Ritchie, October 10th, 1844.

J. Swindells, in his patent of November 14th, 1850, proposes to reduce sulphur ores of copper to oxides by calcination, and then to separate the copper and silver by dissolving them out with ammonia. For the use of a variety of fluxes or of peculiar assortments of ores, the following patents have been obtained; but the advantages resulting from them have not been so great as to become of public interest. Reference is here made to them for the purpose of facilitating further investigation of their character.

De Sussex, March 23rd, 1847, employs with the sulphur ores of copper, siliceous sand, carbonaceous matters, nitrate of soda, soda ash, and fluor spar.

J. J. Hill, March 9th, 1850, uses with the ores, galena, or carbonate or sulphate of barytes or of strontian, and also oxygen gas.

A. Parkes, September 11th, 1851, uses iron or zinc in refining white metal.

Napier's process has been worked on the large scale in Wales; it has for its object the reduction of the ten operations ordinarily employed to one-half the number. In the first place, the ores are selected and mixed so as to contain, as nearly as possible, all the constituents necessary for the production of a perfect fusion of the whole with facility. The raw ore is first roasted in the ordinary calcining furnace, to draw off all the volatile matters as nearly as possible, and to oxidize the remaining metallic constituents. The roasted product is introduced into a reducing furnace, and exposed to sufficient heat to produce perfect fusion. The slags are then skimmed off, and soda ash or sulphate of soda is thrown into the furnace on the melted matt. If sulphate of soda is used, it is employed in the proportion of one to one and a half cwt. to the ton of regulus; twenty to thirty lbs. of fine coal should be mixed with it before it is thrown in. As soon as the salt cake is fused, it should be well mixed over, to produce complete decomposition with the production of soda. After being well mixed with the charge, and allowed to stand for a few minutes, to restore the heat lost by the opening of the furnace and the turning of the charge, the furnace is tapped, and the charge allowed to run out into sand moulds. As soon as the blocks are solidified, and while still very hot, they are thrown into a tank of water, where they immediately crumble down into a sandy mass, which, after being well washed, is removed to a calcining furnace, and there exposed to a roasting for twenty-four hours, or until all the sulphur is as nearly as possible expelled. The product of this third operation is next mixed with oxide or carbonate of

copper, associated with much siliceous matters, and with some carbonaceous matters, such as coal or anthracite, in powder. The charge is put into a reducing furnace, and, in the course of six or eight hours, it is again reduced to a fluid mass. The iron and silica enter into combination with each other, being products of a slag very free from admixture of copper, and metallic copper. The product of this fourth operation is equal in quality to the *white metal* of the ninth operation, and has only to undergo the refining process of the tenth operation to be rendered fit for the market.

The metal obtained is said to be of better quality than that produced by the old plan, in consequence of the sulphide of sodium produced in the second operation having dissolved, when in contact with water, the arsenic, tin, and antimony contained in the ore, and thus removed these bodies in solution. When the slags of the second and fourth operations do not appear to be sufficiently fluid, a small quantity of slacked lime and common salt is added with good effect.

Bankart obtained a patent, August 7th, 1845, which has been worked on an extensive scale near Swansea. The process consists in first reducing sulphur ores of copper to fine powder, roasting them at a low red-heat in a calcining furnace, by which means a large quantity of sulphurous acid gas is evolved; but another portion of the sulphur becomes fully oxidated, is converted into sulphuric acid, and combines with the oxidized copper, producing the sulphate of copper, which is soluble in water. The calcined product is put into vats containing boiling water, which, percolating through the mass, dissolves out the blue vitriol or sulphate of copper, leaving the oxide of iron, undecomposed sulphurets, and siliceous matters behind. These residua are again calcined, with a suitable proportion of the raw ore mixed with them. Through the agency of the water about the ore, and of the peroxide of iron produced in the first calcination, less sulphurous acid is evolved and more sulphuric acid produced, in combination with copper, in this second operation. After suitable calcination, the charge is drawn, and lixiviated in boiling water as before. Copper, in the metallic state, is precipitated from solution by the immersion of metallic iron, or it may be precipitated in the form of an oxide with a solution of soda ash, or by the addition first of muriate of lime, producing chloride of copper and sulphate of lime, which is precipitated. The solution of chloride being run off from the precipitate, the oxide of copper may then be precipitated with milk of lime. The precipitated oxide may be collected and well washed, to remove any adhering saline matters; it is then pressed, and fused in crucibles or in a furnace, with a small quantity of carbonaceous matter sufficient to absorb the oxygen in combination with the metal, in order to produce metallic copper of the very best quality.

A very curious source of copper was brought under public notice by Mr. W. J. Henwood, in a paper read before the Royal Institution of Cornwall, October 31, 1856. In several places in Merionethshire in North Wales, there are peat bogs impregnated with so much copper as will pay for extraction. The most extensive formation of this character is at Dolfrwynog,

where, about forty years since, seventy acres of the bog were worked up. In order to obtain the copper, the peat was cut, dried, and slowly burnt, so as not to produce sufficient heat to slag the ashes, which were collected after all the carbonaceous matter was as completely burnt out as possible. In this manner the whole of the copper diffused through the ton of peat, was concentrated within the hundredweight of ashes, supposing the quantity produced by the burning of the peat to be equal to five per cent. It is said that in one year 2000 tons of ashes were sold at a profit of about £20,000. Similar turbaries are found near the Parys and Mona copper mines in Anglesea.

Although there are but few copper-smelting works on the Continent, yet the processes employed are deserving notice, on account of their admirable adaptation, in many instances, to peculiarities of character of ores, the quality of fuel obtainable, and of the other means at disposal for carrying on the operations. Thus, at Mansfield, in Germany, a peculiar process has been adopted for the treatment of the copper slates, or kupferschiefer, of the district, the character of which is shown in the following analysis by Berthier:

Silica	40·0
Alumina	10·7
Peroxide of iron	5·0
Carbonate of lime	19·5
Carbonate of magnesia	6·5
Oxide of copper	2·0
Sulphuret of copper	6·0
Water and bituminous matter	10·3
	100·0

These schists vary much in constitution, but generally contain not more than from two and a half to six per cent. of copper, with a very small proportion of silver. There is also generally some iron pyrites diffused throughout the mass in minute crystals. In order to drive off as much sulphur as possible, to get rid of the bituminous matter present, to oxidize the metallic constituents, and to prepare the earthy constituents for the subsequent operations, the schist is collected into heaps of from 100 to 200 tons, so disposed as to have flues or draft-holes passing through them, in order to facilitate the combustion of the mass, which is maintained by the bituminous matters of the ore for fifteen or twenty weeks. Some wood is interstratified in the heap to facilitate the combustion. When the calcination is complete, the bulk of the ore is reduced by about one-tenth, and the weight by about one-eighth. It becomes of a dirty grayish-yellow colour, and of a very friable texture. After being mixed with a suitable proportion of flux, consisting principally of fluor-spar, and of slag from the same operation, it is thrown into a blast or cupola furnace with coke, or a mixture of coke and charcoal. The front elevation and vertical section of the furnace are shown in Figs. 143 and 144. By the maintenance of the blast, the mixture is fused, and passes through the fuel to the bottom of the furnace, whence it is allowed to run out into basins sunk into the external hearth. The matt,

containing nearly the whole of the copper, sinks to the bottom of the basin, and the siliceous slag is from time to time raked off. In this manner about four tons are melted away every twenty-four hours, yielding eight to twelve per cent. of matt, containing thirty to forty per cent. of copper. The slag, which sometimes contains as much as ten per cent. of copper, is melted over again, to obtain more matt, in which all the copper, as nearly as possible, shall be concentrated; and the fused slag separated from the matt is run into moulds, for the formation of bricks and blocks for building houses, walls, and for constructing pavements. The matt produced in the first operation contains sulphurets of copper, and of iron, zinc, cobalt, nickel, arsenic, and silver. It is roasted either in heap or in kiln, with wood or charcoal, three successive times, the operation lasting about four weeks; or, according to a more recent improvement, the calcinations are effected in a reverberatory furnace, precisely similar in construction to that employed for the first operation of the English process. By these successive roastings, some sulphur is expelled, most of the arsenic is volatilized, and some sulphate of copper is produced, which by lixiviation is separated. By evaporation, the solution thus obtained is concentrated, and the sulphate of copper is procured as blue vitriol in the crystalline form. The residuary roasted matt is fused in another cupola with some ore cinder, and another matt is produced containing fifty to sixty per cent. of copper, and sulphurets of copper, iron, and silver. This concentrated matt (spurstein) is obtained in the proportion of forty to sixty per cent. of the roasted matt. A single furnace will run down from thirty to forty hundredweights of the matt in twenty-four hours.

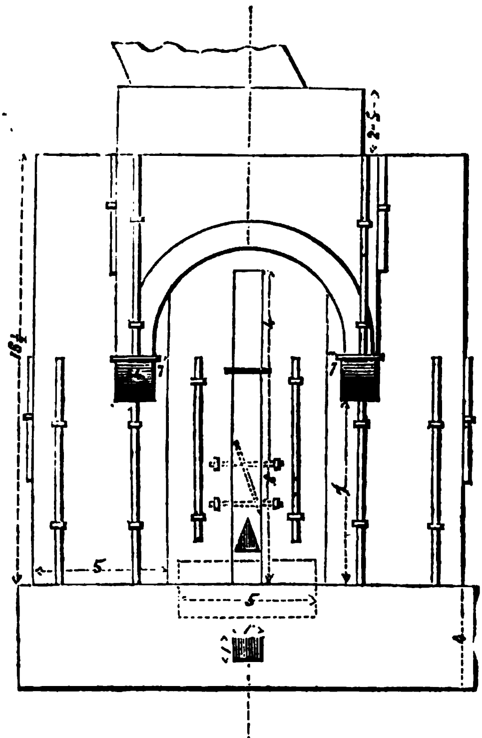


Fig. 143.

The spurstein is m ixed with a proportion of the matt of the first fusion,

and is roasted six successive times in a kiln, or with the expenditure of very much less time in the reverberatory furnace, as before described. If done in the old way, the six calcinations occupy about seven to eight weeks. After the calcination in the reverberatory furnace, or after each of the series of calcinations in the kilns, the charge when drawn is lixiviated, for the separation of the soluble sulphate of copper, as before. It is now known as gahrrost, having a bright red colour and a granular fracture. It consists principally of oxide of copper, with some metallic copper, some iron, and but a small proportion of sulphurets. It is again mixed with a small quantity of slag, the product of former operations, and is smelted in a smaller cupola furnace, through which three to four tons of the gahrrost is passed in the twenty-four hours. The products are black copper, a rich matt called dunnstein, and a slag. The black copper is obtained in the proportion of one quarter, and the dunnstein in that of one-sixth. The black copper is found at the bottom of the basin, the dunnstein over it, and the slag on the top of all. The slag is skimmed off, the crust of dunnstein, as soon as sufficiently solid from cooling, is separated, and finally the black copper is taken off in thin cakes the size of the basin, produced by throwing cold water on the surface, and removing the cooled portion with an iron bar; the cooling and removals are repeated until the contents of the basin are exhausted. While the one basin is being emptied, the other is being filled from the cupola.

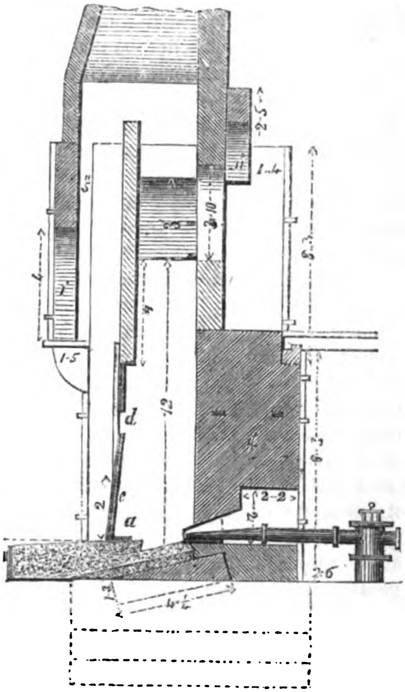


Fig. 144.

The black copper obtained from the Mansfeld copper schists generally contains silver in quantities varying from 80 to 200 ounces to the ton. The constituents are as follow:—

Copper	95·0
Iron	3·5
Sulphur	1·0
Antimony, silver, zinc, &c.	·5
	100·0

The matt and the slags are sorted and used over again in the various operations previously described. Although the operations involved in the Mansfeld process are so very different in appearance from the operations employed in the English process, yet the principles are the same; the object in both cases being to evolve by heat all substances capable of being volatilized, at the same time producing such an oxidation of the non-volatile constituents as will best suit the conditions necessary for effecting the combination of them with the earthy matters present, so gradually—first separating all the earthy matters with some of the metallic oxides, then evolving the iron by bringing back siliceous matters to act as the solvent, throughout the whole series of operations making the sulphur, in combination with the copper, play the important part of rendering the copper so much more fusible than the other metallic oxides and earthy matters,—that when they are all melted together, the sulphuret of copper, by its greater specific gravity, falls to the bottom, and is thus at once permanently obtained in a separate condition from all the waste constituents of the original ore. Finally, in both instances the means are adopted for removing the hitherto useful sulphur, together with any residuary traces of other metals. The principal differences in the operations are, that in the English process large reverberatory furnaces are employed, without any mechanical aid, in the production of the necessary heat; while in the Mansfeld process, when great heats are required, they are obtained by the employment of small cupola furnaces, in which the heat is produced with the assistance of a blast. On close comparison of the processes, it is found that, while the Mansfeld process is characterised by the expenditure of a large amount of time and of labour, with economy of fuel, the English process is distinguished by great economy of time and labour, with a comparatively large expenditure of fuel. It does not hence follow that in either case the one process is to be considered superior to the other, because each is best suited to the locality and circumstances under which it is conducted. In Mansfeld, economy of fuel is a greater desideratum than that of labour or of time; in Wales, fuel is so cheap that economy of labour and of time is of very much greater importance.

When the black copper contains sufficient silver to pay for extraction, it is subjected to a process of liquation; which consists in the sylliquation or melting together in a cupola furnace of the black copper, with lead or litharge, containing silver, in the proportion of one part of black copper with four parts of lead. As the alloy is melted, it is drawn off from the furnace, and cast in iron moulds into loaves, or large dishes thirty inches in diameter and seven inches thick. When the furnace is charged, the weight of black copper in small pieces is first put in on the fuel; the proportion of litharge or metallic lead is then added, and on it another charge of fuel, consisting of coke or charcoal. The fusion takes place rapidly on the blast being set on, a loaf being cast away every ten minutes. Any slag formed is skimmed off from the basin or crucible into which the charge is run, before it is ladled out into the moulds. The sylliquation furnace is a low blast-furnace about four feet high, two feet wide at the tuyère, or from front to back, three feet

across in the other direction, and opening slightly in the upper part. The tuyère projects three or four inches into the furnace, having a downward direction, the bottom of the furnace sloping from the tuyère to the teasing-hole or eye of the furnace in the front of it. The furnace is nearly of the same construction as that shown in Figs. 139 and 140 (page 541), which is used for the first smelting of the raw ore. In apportioning the materials for the charges for the sylliquation process, it is of great importance to have neither too much nor too little lead. If too much lead be used, it will cause the whole mass in the subsequent operation of eliquation to run down; whereas the object is to wash out the silver from the copper, leaving the copper in a porous condition, retaining the original form of the loaf. If an insufficient quantity of lead be employed, a portion of the silver will be left behind. The best proportions are about—

Silver	1
Copper	150
Lead	512
Each loaf will weigh about $3\frac{1}{2}$ cwt.	663

The eliquation process is conducted either in the reverberatory furnace, shown in the annexed Figs. 145 and 146, or on an open hearth, as shown in Figs. 147 and 148. In the reverberatory furnace, the loaves are set on edge on slightly-inclined plates of cast-iron, as seen at H. The heat from the fire-place B, passing over the loaves, causes the melting of the lead, which runs down on the cast-iron plates, and thence into the chambers G below, where a channel is provided for conducting the liquid metal into a suitable receiver; whence it is filled out into moulds of a suitable size for subsequent operations on the argentiferous silver, for the extraction of the silver. In the open hearth (Figs. 147 and 148), the loaves are placed edgeways on the iron plates A, charcoal being placed between them; and the space G below is filled up with wood and charcoal. The loaves being covered with charcoal, and thick plates of iron laid over all, the fire is lighted; and as the fuel surrounding the loaves is consumed, the lead is eliquated, falls down on

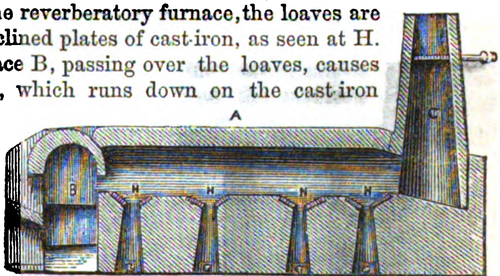


Fig. 145.

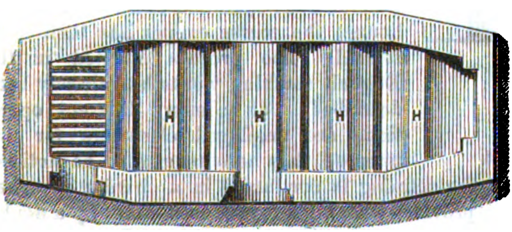


Fig. 146.

the iron plates, thence into the chamber below, and on into the iron basin B, whence it is filled out into the moulds C.

In the large reverberatory furnace, sixty loaves are treated at once; in the smaller open hearth, only six are operated on at one time. In the eliquation furnace, the whole of the silver lead is not obtained from the copper, as a much stronger heat is necessary for the extraction of the last traces of lead, and with it those of silver. To remove these, the eliquated copper is removed to another furnace, for the darring or sweating operation. This furnace is sufficiently large to take about 120 eliquated loaves at a time; it is a sort of reverberatory furnace, the fuel of which is wood, being burnt in flues under the sole on which the charge is laid, the flame rising up at one end of the furnace, passing over the charge, and thence to the chimney. The sole has a slight inclination to carry off the melted lead as it falls out of the copper. The heat is maintained briskly, until the droppings begin to assume a reddish coppery appearance; the fuel is then withdrawn, and the coarse copper is taken out and thrown into water. This operation takes about twelve hours; the coarse copper has then to be refined. The process adopted in the English smelting works has already been described; but as many different operations are employed elsewhere for this purpose, they here require to be noticed.

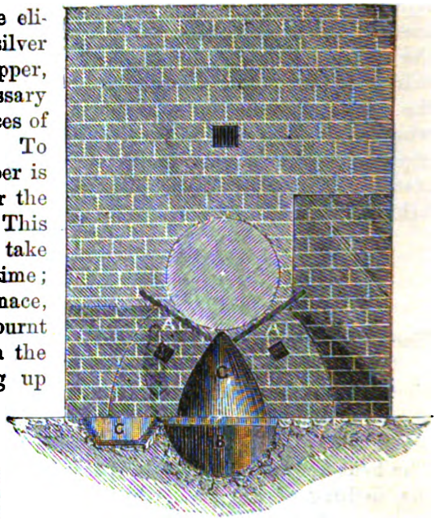


Fig. 147.

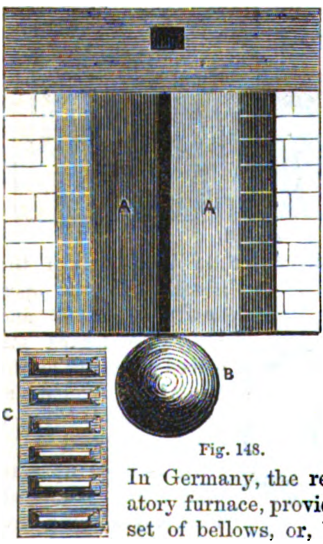


Fig. 148.

In Germany, the refining is conducted in a circular reverberatory furnace, provided with a blast, produced either by a double set of bellows, or, better still, by cylinders. The furnace is made sufficiently large to hold fifty cwt. of coarse copper at a time. The pieces of coarse copper are piled in the furnace one over another, leaving only sufficient room for the current of heated gases passing through

the furnace from the fire-place to permeate the mass. As soon as the charging of the furnace is completed, it is carefully closed up. The furnace is slowly heated, taking six hours to bring it to a red-heat: this slowness is necessary only when the bed of the furnace has been newly repaired. When in regular course of work, only two to three hours are required for this purpose. At the end of this time the blast is put on, the coarse copper gradually becomes pasty, then slowly liquefies, until the whole mass is melted in about six hours from the time of setting on the blast. During this time a charcoal fire is kept up in the receiving basin, for the purpose of getting it sufficiently hot to receive the liquefied metal. A small fire is also maintained around the tap-hole. Shortly after the charge is perfectly fused, the working-door is opened, a shovelful or two of moistened ashes are thrown over the surface of it for the purpose of chilling the slag, which is then removed with an iron rake. The furnace is again closed. The slag removed contains—

Silica	27·5
Protoxide of iron	57·9
Deutoxide of copper	2·0
Alumina	1·3
Sulphur	4·2
Iron	6·8
	99·7

The refining now commences. The blast is thrown down on the surface of the copper, and immediately oxidation commences, producing scoria, which is removed from the surface of the metal as it is slowly formed, so as to allow of the constant action of the air. This operation continues four to five hours. The first scoria produced consists of—

Silica	13·0
Protoxide of iron	75·0
Deutoxide of copper	3·5
Sulphur	2·5
Alumina	0·2
Iron	4·2
	98·4

The second scoria contains—

Silica	26·2
Protoxide of iron	66·0
Oxide of copper	4·0
Sulphur	1·3
Iron	2·2
	99·7

When the formation of the scoria ceases, the whole of the iron will have been separated, and only a small quantity of sulphur is left in combination. The continuous action of the blast converts the sulphur by oxidation into sulphurous acid, which passes off first in tubbles, rising through the metal

to the surface here and there; these increase in number gradually, until the whole mass is in a violent state of ebullition; and although the heat be maintained, it gradually ceases. The *working* of the metal ceases with the evolution of the last portions of sulphur. As the operation proceeds, samples are taken from time to time by dipping a rod half an inch in diameter, polished and rounded at the end, through the tuyère hole into the bath of metal, withdrawing it quickly, and plunging it into water. The piece of copper surrounding the end of the rod is broken off with a hammer. According to the different stages of the process at which the samples are taken, so are they characterised as—

	Iron.	Sul.	Ox.
1. After the first skimming off the scoria, it is smooth, pale red, spotted with black, brittle, blackish-red in the fracture, and contains	6·0	1·1	0·0
2. An hour later, rough, dull red, spotted with gray and brass yellow, brittle, of a clearer red in the fracture, and contains	3·0	0·5	0·0
3. Two hours later; surface rugged, reddish-violet, spotted with gray, less brittle; the fracture of a clearer red, and containing	1·2	0·5	0·0
4. At the commencement of the *working* of the metal; surface rugged, reddish-violet, malleable, and containing	0·0	0·4	0·3
5. At the end of the working; mammillated, porous, deep red, malleable, pure copper, red in the fracture	0·0	0·0	0·6
6. At the moment of tapping the furnace, the test sample taken is mammillated, smooth, presenting a few cavities on the surface, of a beautiful carmine red, or of a very bright blood-red colour, slightly malleable, tearing under the hammer; the fracture of a pure copper red, with a tint of carmine, containing	0·0	0·0	0·8

When the charge has attained the degree indicated by the last test, the furnace is tapped, and the liquid metal is allowed to run out into the basins which have been prepared by maintaining a fire in them. The fuel is removed from the surface of the metal with the scoria; and when quite clean from skimming, the surface is covered with a sort of smoke, produced by the scintillation of very minute particles of the oxide of copper. To stop this formation, the surface is cooled by blowing on it; as soon as the crust is formed, a little water is thrown over it to further chill it, and produce a sufficiently thick cake, for removal to a cistern of water, kept cold by a running stream; successive crusts are removed and cooled in this way until the basins are emptied. These discs are termed rosettes; they require to be cooled in the manner described, in order to be brought to the colour desirable for commercial purposes. These rosettes are divided into smaller portions for the market. When wanted in the form of bars, bolts, plates, or sheets, they are cast over again.

If, at the moment of tapping the furnace, the melted metal contain too

much oxide of copper, it becomes pasty and of too deep a red colour, and the rosette becomes too thick and difficult of management in removal. To correct this defect, a few pounds of lead are added; the cakes of copper become sufficiently thin, without its ductility or malleability being affected; but its tenacity is injured. One thousandth part of lead is sufficient to prevent the copper being drawn into wire; and it gives to the copper the property of tarnishing very rapidly in the air. The appearance of micaceous scales in the test, when fractured, indicates the presence of oxide of copper or of antimony. The latter metal is derived principally from the lead used in the sylliquation process. As it is very difficult to separate perfectly, it is of importance to avoid the use of hard lead containing this metal, as the copper produced from it cannot be used either for making sheets or wire, being too hard and brittle, and of a yellowish colour.

In the cooling of the plates of the rosette copper, it is necessary to be very careful that the whole of the metal be solidified before it is put into water, as otherwise dangerous explosions may occur.

But a small proportion of copper is used without being alloyed with other metals; as these alloys are of great importance in the arts and manufactures, we shall devote some space to their consideration.

Alloys of Copper.—Copper in the pure state requires a great heat for its fusion; and when cast, has a great tendency to become porous. This may, to a certain extent, be obviated by the use of a small quantity of phosphorus, mixed into the pot of metal when ready for casting, immediately before it is poured. This effect is also produced by the addition of about two per cent. of zinc. The metal is also too soft alone for general purposes; and as, moreover, it is more costly than most of its alloys, which will for common purposes generally serve equally well, if not better, its use is economized as much as possible. The principal alloys of copper with other metals are as follow:—

ALLOYS OF COPPER.

	Copper.	Zinc.	Tin.	Lead.	Nickel	Anty.
Antique bronze sword	87·000	—	13·000	—	—	—
Do. springs	97·000	—	3·000	—	—	—
Bronze for statues	91·400	5·530	1·700	1·370	—	—
Do. for medals	90·000	—	10·000	—	—	—
Do. for cannon	90·000	—	10·000	—	—	—
Do. for tamtams and cymbals	78·000	—	22·000	—	—	—
Do. for gilding	82·257	17·481	0·238	0·024	—	—
Do. do.	80·000	16·500	2·500	1·000	—	—
Speculum metal	66·000	—	33·000	—	—	—
Brass for sheet	84·700	15·300	—	—	—	—
Gilding metal for jewellery	72·730	27·270	—	—	—	—
Pinchbeck	80·000	20·000	—	—	—	—
Prince's metal	75·000	25·000	—	—	—	—
Do. do.	50·000	50·000	—	—	—	—
Dutch metal	84·700	15·300	—	—	—	—
English wire	70·290	29·260	0·17	0·28	—	—
Mosaic gold	66·000	33·000	—	—	—	—

ALLOYS OF COPPER—*Continued.*

	Copper.	Zinc.	Tin.	Lead.	Nickel	Anty.
Gun-metal, for bearings of machinery and steam-cocks, &c.	90·300	9·670	0·03	—	—	—
Muntz's metal for sheathing . .	60·000	40·000	—	—	—	—
Good yellow brass for turning and filing for machinery .	66·000	33·00	—	—	—	—
Do. do.	80·000	20·00	—	—	—	—
Babbitt's metal for bushings . .	8·300	—	83·00	—	—	8.3
Bell-metal for large bells . . .	80·000	—	20·00	—	—	—
Do. for small do.	—	—	—	—	—	—
Britannia metal	1·000	2·00	81·00	—	—	16·0
Nickel-silver, English	60·000	17·8	—	—	22·2	—
Do. Parisian	66·000	13·6	—	—	19·3	—
German-silver	50·000	25·0	—	—	25·0	—

The specific gravity of brass is greater than the mean of its constituents, varying from 7·82 to 8·73; that of copper being 8·78, and of zinc 6·86. The density of the tombac metal, composed of copper 87·5 and zinc 12·5, when drawn into wire, has been found as high as 9·0

Brass was formerly manufactured from copper in the form of bean-shot, or clippings, and the oxide of zinc, obtained by the calcination of calamine or carbonate of zinc, mixed together with powdered charcoal in crucibles, and exposed to a strong white heat. By this process a combination of a greater proportion than 28 of zinc with 72 of copper could not be obtained, the product being known by the French as *arcol.* If a larger proportion of zinc were required in the compound, it was necessary to remelt the arcol, and to add the proportion of zinc required. The proportions employed were equal parts of calcined calamine and metallic copper, with one-third of the united weights of powdered charcoal.

In the year 1781 a patent was obtained by James Emerson, for the manufacture of brass direct from its metallic constituents; but the old plan has been still pursued until a comparatively recent period. From the improvements that have been making in the smelting of zinc, by which the cost of this metal has been greatly reduced, it has been found much more economical to make brass entirely and exclusively at one operation from the two metals. Instead of the oxide of zinc of calamine, the same substance, obtained by the calcination of blende, black-jack, or sulphuret of zinc, was also sometimes employed.

Brass is manufactured on the large scale in crucibles heated in a furnace whose diameter is about five feet; its height, from the sole to the crown, is the same as the diameter. Instead of fire-bars to support the fuel, the bed of the furnace consists of an iron plate, on which is a layer, about two inches thick, of refractory fire-clay, firmly beat down, but perforated with thirteen holes corresponding with similar holes in the iron-plate. Through these holes are placed conical cast-iron frames, around which, and level with the top of them, the fire-clay bed is laid. These frames are about four inches in

diameter in the clear below, and two and a half inches above. These serve as draught-holes for supplying the air necessary for the consumption of the fuel placed around the eight crucibles equally distributed over the sole of the furnace. The mouth of the furnace is furnished with a cast-iron collar, and is from twelve to sixteen inches in diameter; it is also furnished with a fire-tile cover. Several of these furnaces are placed side by side, so as for their flues to communicate with one chimney. The crucibles are best made of the same quality of clay, and in the same manner, as for glass making; they usually last from a fortnight to three weeks, if well made and carefully used. They contain from one hundredweight to one hundredweight and a quarter of melted brass. Either coal or coke is used as fuel. When the interior of the furnace, with the charge of empty pots, has been raised to a red heat, each pot is in succession taken out of the furnace, then charged with the metal, and replaced. The furnace is filled up with fuel, and the heat maintained until the whole of the charge is perfectly melted, which it usually is in about three hours. The fused brass is poured out into granite moulds, or into open sand, for the formation of the ingots, to be used for remelting. Commonly no flux is employed in assisting the combination of the copper and the zinc; but in several foundries, the author's recommendation to employ soda ash, either alone or in combination with slacked lime, has been adopted with advantage. A few ounces only of the mixture is sufficient for a pot of thirty to forty pounds of metal. When the metal is required for running very thin castings, if, after the skimming of the pot, half an ounce of dry phosphorus be rapidly stirred in, castings may be successfully run that would otherwise have been very liable to fail. The phosphorus causes the metal to become much more liquid; and, when cold, to attain a greater density, as indicated by its specific gravity, than it would otherwise have obtained. As considerable accumulations of skimmings, turnings, filings, &c., take place in foundries, it becomes necessary to render them available. This is usually done by washing, sifting, &c., before fusing in a crucible with sal-enixum or sulphate of potash; but very much of this labour may be avoided, and better results obtained, by at once fusing the mixture with soda ash.

Brass is largely employed not only for the taps, but also for the ornaments of gas-fittings. Some of these ornaments are finished off in the turning-lathe, with the chisel, file, and polishing-tool, the finished surface being protected with a coloured, or, better still, with the best metal, if a gold colour be required, with a fine colourless lacquer made with spirits of wine and gums. But other portions, which will not bear the cost of tooling for bringing up the surface, are cast up to the required form at once, and the required surface produced most rapidly and ingeniously by dipping the work in a bath of "dipping acid," composed of nitric acid, sulphuric acid, and muriate of ammonia, or sal-ammoniac. The mixture should be so strong that only a momentary dip should be sufficient to make the object bright and clear, however rough it may have been. It should then immediately be well washed in cold, and finally in boiling water. It is sometimes dried off

in warm bran or fine saw-dust. The beautiful surface thus produced is commonly protected with a covering of lacquer; but it will for many months withstand the ordinary influences of domestic life without such aid.

From the high temperature necessary for the fusion of copper, a considerable loss of zinc might have been anticipated in the manufacture of brass, as the latter metal is volatilized at a much lower temperature than the fusing-point of the alloy; but the affinity of the two metals for each other is such as, with proper management, renders the loss inconsiderable.

If the zinc be first melted, and copper plunged into it, the formation of the alloy will immediately commence, without the fusion of the copper. Copper plates and rods are sometimes partially converted into brass, by simply exposing them, at a high temperature, to the vapour of volatilized zinc. Copper vessels may also be partially converted into brass by boiling them in dilute muriatic acid with wine stone argol, or crude tartrate of potash, and an amalgam of zinc. The best proportions for fine brass appear to be those of the chemical equivalents of the metals,—viz. 2 copper 63·3 $\times$ 1 zinc 32·57, or about two parts of copper and one part of zinc.

For rolling into plates or sheets, and for drawing into wire, it is necessary that the brass should be made exclusively of copper and of zinc; but a better metal for turning purposes is produced by the admixture of about two per cent. of lead. Brass laminates well in the rolling-mill cold, as long as it is kept sufficiently soft; but as by lamination the metal hardens and becomes brittle, it is necessary to restore its tenacity by annealing in an oven or reverberatory furnace. The same process of annealing is necessary in the manufacture of brass wire, which is obtained by drawing it through holes in steel plates, polished carefully and adjusted in series, graduated in size, so as not to diminish two rapidly, and thus render it necessary to employ so much power for drawing as would cause the breaking of the wire.

Brass is not usually so prepared as to admit of its being hammered out, as is done in the manufacture of copper utensils; but a brass-foil or Dutch metal of the colour, and approaching the thinness, of gold-leaf, is manufactured by beating out thin sheets of brass with hammers worked by water-power, making 300 or 400 strokes per minute. Brass sheathing, known as Muntz's metal, is now largely employed as a substitute for copper, for covering ships' bottoms; a variety of the same metal is also used for drawing into tubes for steam pipes and flues of locomotive boilers. They are much less costly than the copper tubes ordinarily employed for these purposes. In all the various white metallic alloys used for domestic utensils—such as German silver, nickel silver, britannia metal, &c., whether intended to be used as they are, or as the basis for covering with silver by electrotype processes —copper forms the most important constituent.

CHAPTER XXVIII.

TIN, ITS ALLOYS AND SYNONYMES.

Synonymes: Etain, *Fr.*; Zinn, *Ger.*; Stannum, Jupiter.—As it is most easily obtainable from the pure native oxide, with the aid of heat and charcoal alone, it was early known to the ancients. It is spoken of by Moses; it was obtained by the Phœnicians from Great Britain, and from Spain. It much resembles titanium in its chemical properties, the corresponding compounds of the two metals being isomorphous.

Tin Mining.—Tin in its refined state has a colour and lustre approaching to that of silver, but is slowly tarnished by exposure to the atmosphere. It is harder than lead, very malleable, and may be laminated into foil or leaves of tin of exceeding thinness, but cannot be drawn into wire. Rubbed or otherwise subjected to friction, it exhales a peculiar odour, and communicates to the tongue an unpleasant taste. Rods or strips of pure tin are flexible, but devoid of elasticity: the bending of thick bars produces a crackling sound, as if fibres of metal were being slidden over each other—probably occasioned by the disturbance of the constituent crystals.

According to Kupffer, tin melts at 446°; Crichton makes it 442° Fah. In close vessels it bears high temperatures without volatilization or sensible loss. It boils at a white heat; its specific gravity is 7·291, but may be increased to 7·302 by condensation of the particles.

Heated to redness in contact with atmospheric air or free oxygen, it loses its metallic lustre, rapidly passing into the gray protoxide; by continuing the operation, the tin absorbs a further equivalent of oxygen, and is converted into a yellowish-white powder, the peroxide, more commonly termed "putty" of tin. The protoxide consists of tin 87·64, oxygen 12·36 = 100·00; the peroxide of tin 78·61, and oxygen 21·39 = 100·00. In its pure state, tin is scarcely acted upon by dilute acids and reagents. Nitric acid of moderate strength acts upon it; not dissolving it, but converting it into a white powder, with energetic action and evolution of heat.

The applications of the metal in the arts are exceedingly numerous. The tinning of iron plates and hollow ware goods, generally for domestic purposes, is one important application. Bronze and gun-metal owe much of their valuable properties to its presence. Cymbals, Chinese gongs, and bells, are dependent on the presence of tin for their peculiar tones. Reflectors of telescopes, and the standard measures used by Government, are made of an alloy in which tin largely enters. Imitation gold, britannia metal wares, common pewter, and a number of minor alloys, are produced with its assistance. Solders form an important feature in the uses of tin; plumber's solder, tinman's solder, pewter solder, and other similar applications of the

metal, are too well known to require detailed description. With mercury it forms the valuable amalgam used in silvering mirrors.

The pale yellow anhydrous peroxide is largely used by jewellers in polishing, under the name of *putty powder*. The white enamel inside certain kinds of pottery ware is composed, in part, of tin oxide. It is also used to render glass white and opaque, as in the preparation of the enamel for the dials of watches, and the manufacture of artificial gems. Other compounds of tin are of important application: nitrates and chlorides are largely used in dyeing; while a compound of tin and gold precipitate gives the beautiful *purple of Cassius*.

Tin Ores.—The known ores of tin are limited to two: cassiterite, or tinstone; and tin pyrites. The peroxide of tin sometimes, though rarely, occurs massive, fibrous, granular, and crystallized; in colour, all shades from light-brown to black: and in the Mount's Bay, Cornwall, the oxide of tin has been met with, in white, translucent, glassy crystals (tin diamonds) of great beauty. The oxide of tin belongs almost exclusively to the oldest of the primitive mountains, but not to the oldest granite. It is found in irregular veins, pockets, or bunches; a continuous well defined lode of tin-stone is not a frequent mode of occurrence. It is disseminated in certain descriptions of granite, but in too small quantities for working economically on an extensive scale. The veins are of various descriptions: the stanniferous ore sometimes occurring in thin flat masses or floors, parallel with the bed of the rock, apparently without connection with the adjacent veins. These, though small, are often numerous, and at their junction commonly display to the miner a paying deposit of ore.

Tin pyrites (sulphuret of tin) occurs massive; colour steel-gray, yellowish-white, or yellow, and buff: at times specimens are found exhibiting all four colours irregularly. Its fracture is granular and uneven, passing into conchoidal of a shining lustre. Composition: tin 36, iron 2, copper 36, sulphur 26 = 100.

The peroxide of tin is the only ore of the metal extensively used. In Cornwall the largest mines are in the neighbourhood of St. Agnes, Gwenap, Helston, St. Ives, and Penzance in the west, and St. Austle in the east. Small quantities are mined near Tavistock in Devonshire. The most celebrated mines are Wheal Vor, near Helston; Polberrow, near St. Agnes; Polgooth, near St. Austle; Drake Walls, near Tavistock, on the Cornish side of the Tamar; and Birch Tor, or Vitifer, also near Tavistock, but on the eastern side in Devonshire. Some of these mines have been worked from the most remote antiquity; have been successively abandoned and worked as an increased demand and improved value of the metal, or the development of greater facilities of working, has allowed of the work being resumed with profitable results. Next to the Cornwall mines, those of the Malayan Peninsula and Banca produce the largest quantity of tin. Spain, Bohemia, Saxony, France, and one or two other states in Europe, produce small quantities only; as also do Chili, Peru, Mexico, and other American states. Recently Australia has exported small quantities of auriferous tin

ore; and looking at the known stanniferous character of the Australian Alpine chain, there is reason to believe that in a few years the supply of tin from that continent will materially affect the prosperity of the Cornwall mines.

Sulphuret of tin has been worked near St. Agnes, Redruth, Constantine, St. Austle, and other places, in very limited quantities. It is probable that future researches into the constituents of apparently worthless substances will open up other sources of obtaining tin.

Mining of Tin Ores.—This is performed in nearly the same manner as for copper ores. The description there given of the mode of sinking shafts, driving levels, winzes, and other dead-work operations; extracting the ore, the modes of ascending and descending the mines, absence of ventilation, drawing the ores, and draining the deep workings of water, applies equally to tin mines, and, it may be added, to lead also. At the surface, the dressing of tin ores for sale is conducted on the same principle, but in a different manner from that pursued with copper ores.

Cleaning Tin Ores is commenced at the surface, by breaking the stones and separating the product of the mine into heaps of different qualities, according to the richness of the tin ore, or the nature of the gangue. If merely of stony matter, the ore is divided into two or three qualities, according to their apparent richness, in order to diminish the loss in dressing; but such as contain copper, pyrites, and some other substances, are placed in a separate division, to be dressed apart from the others. Ores containing wolfram require special treatment for the elimination of the tin which they contain.

The first operation to which the ores are subjected is the stamping. The stamping-mill is an apparatus in constant requisition in tin mines. It consists essentially of a number of cast-iron pestles, measuring twenty inches high, and six inches by ten in the beating-face, secured by castings or keys to a narrow wrought-iron shank, or by sockets to a wooden stalk. In its vertical movement the shank carries on its upper part a projecting-arm, and at bottom and top is guided by suitable metal or wooden supports. A revolving shaft is in front, armed with four or five projecting cams, each of which catches in the arm, and lifting the pestle eight or ten inches, lets it suddenly fall on any substance underneath. The hard tin-stone rapidly wears away the metal of the beating-head; and to compensate for the shortening going on, the projecting-arm is constructed that it may be slidden up or down, to meet the wear of the pestle, or other irregularity. The bottom on which it works is formed by allowing it to stamp for a short time dry or hard stones, or other similar material.

Around four pestles a wooden box is constructed, and covered in at top to meet the lower guides of the shanks. The sides of this box are continued upwards to carry top-guides, and to steady this portion of the apparatus in the rear. The back is partly open at the bottom to admit the tin stuff. In front two, and on each side one orifice, seven or eight inches square, are cut out of the wood near the bottom, and fitted with cast-iron frames, containing

perforated iron, copper, or brass plates, the bur of the punch or drill towards the inside. As a precaution against its speedy destruction by the violently scattered fragments of stone, the inside of the box is partially lined with iron plates.

Tin-stone is supplied on an inclined plane or hopper at the back, where also a small stream of water enters the box. The product of the stamping is received in front and at the sides into wooden channels, and directed to the dressing-floors.

With water-power, the number of heads is limited by the quantity of water and fall: three is the least number used, but four or some of its multiples is a preferable number. If steam-power is used, the number of heads or pestles driven is limited only by the requirements of the mine; in some productive tin mines twenty-four are employed, while in others ninety-six are kept at work day and night throughout the week. The employment of steam-power, however, necessitates the adoption of mechanism for preventing injury to the stamping apparatus, by an accidental reversal of the motion given to the shaft carrying the projecting cams. A side-view of the safety coupling invariably attached to the end of the crank-shaft of each steam-

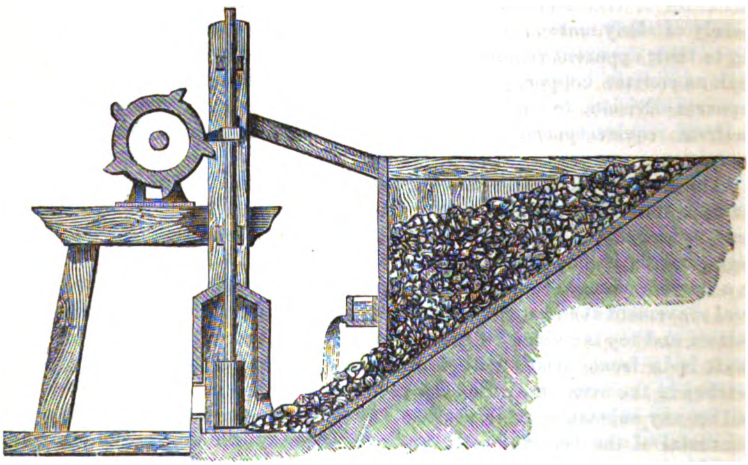


Fig. 149.

engine used for driving a stamping-mill is given in Fig. 149. By means of the catch-levers in the part attached to the crank-shaft, acting on the teeth of the other part to which is connected the axle carrying the cams, motion is communicated to the latter only when the engine-shaft revolves in the proper direction.

When in action, the pestles, or stamp-heads as they are commonly called by the miner, are elevated forty to eighty times per minute. The distance through which they are elevated varies in different stamping-mills, as also in the same mill, through variation in the length of the stamp-head from the

lifting-arm. Ten inches may be considered an extreme lift; seven inches a minimum. The repéated blows of the pestle-head crushes the ore to fragments; and reacting on it till reduced to a powder sufficiently fine to pass through the perforations of the iron plate, violently ejects it with the water. The pulverization is greatly facilitated by having four pestles in the same box, placed side by side, and no more than two or two and a half inches apart. Each pestle is lifted separately; and the cams by which this is done are so disposed on the periphery of the axle that the blows are given in regular succession, so long as the apparatus is in regular motion. If the mill consists of more than four pestles, the cams of the entire number, however large, are so accurately disposed on the axle that no two pestles of a mill of ninety-six can fall at the same instant. Much difference of opinion prevails as to the order in which the lifting of four in one box should take place; whether one of the inner pestles should precede the other, or whether a side pestle should be first lifted. A preference, however, seems to be given to the following order, supposing the spectator to stand in front of a four-pestle battery:—Left side pestle first, right side second, right middle third, left middle last. Long experience has demonstrated that the stamping is best performed with this order of lifting. Scattered by the blow of one pestle under the partially lifted adjoining pestles, the tin-stone which enters the back of the box is subjected to from 160 to 320 blows per minute, from pestles weighing between 300 and 400 lbs. each when new.

The small holes in the stamps-grate allow the ore to pass only when reduced to a fine sand. At six or eight feet from the perforated plates, in front, are two large cisterns, eighteen or twenty inches wide, ten or twelve deep, and having nearly this quantity of declination in a length of fifteen or sixteen feet. These cisterns are connected with the battery by channels and small sluice-gates, by means of which the entire product may be conveyed to one cistern while the other is being emptied of its accumulations. From the lower ends of the cisterns the mineralized water runs into a common channel, to an excavation in the ground known as the "slime pit," where it deposits much of the slimy matter in solution. A second slime pit is kept in reserve, to be used whilst the other is being emptied. If the mill is a large one, there will be a slime pit for every eight or ten pestles. If the water still contains a notable quantity of solid matter, it is passed into other pits till nearly the whole has been deposited. The water of extensive mines is commonly charged with stanniferous matter for a considerable distance from the works; and numerous streamers purchase of the mine-owner the privilege of extracting such portions as they may be able to do with their rude apparatus—those nearest the works paying the heaviest royalty.

In the long cisterns, the roughs or coarse particles of the ore are deposited, the largest and heaviest at the head of the cistern,—the value of the deposit being nearly in an inverse ratio to its distance from the entrance of the ore and water. The contents of the cistern are divided into three; and the treatment of the several portions, though varying to some extent with the character of the ore reduced, and local usage, may be described as follows:—

The upper portion is taken in barrows to a buddle of the ordinary description, and passed through with great care. It consists of a rectangular cistern made of wood plank, eight feet long, four feet wide, and two feet deep, declining about one inch in the foot lineal. At the lower end a series of plug-holes are drilled, to let out the water used in the process at such levels as the height of the contents may require. The ore is delivered into a kind of shallow hopper, ten or twelve inches wide, grated in front, and is washed down by a small current of water to the head of the buddle, where a number of small spreading ledges divide it into twenty or thirty minute streams. Entering at so many places in the head-board, the small streams join in the descent, and form a broad flowing sheet over the entire bottom of the buddle. The heaviest particles of ore are left at the head of the sloping bottom; and this order continues till the cistern is filled. Care is taken that no irregularity occurs in the intensity of the stream in any one part. The formation of furrows, which would militate against the correctness of the results, is prevented by a free use of the brush or feather in the hands of the boy attendant. When filled, the length of the cistern is divided into two or more portions, the treatment of which varies; but commonly the head is passed through the "tossing" or "chimming" process.

The tossing-tub, or "kieve," consists of a stout wooden vat, bound around with iron hoops, of a capacity ranging from 100 to 150 gallons. Water is thrown into it, and a quantity of ore added. With an iron shovel, a man stirs the mixture as the ore is being thrown in, and for five or six minutes subsequently; a slight subsidence having taken place, he bales out a small quantity of water, and facilitates the further subsidence of the ore by "packing" the kieve. This consists in striking its sides with a hammer for nine or ten minutes. The denser parts subside most rapidly, the larger particles first and the lighest last of all. After complete subsidence, the water is drained off, and the mineral is found occupying distinct layers, as in the section; the uppermost is thrown out as being of little value, but it is sometimes re-dressed; the next is reserved for further washing; while the bottom layer, with the exception, perhaps, of a small portion of coarse particles in the centre, is considered clean ore, or, if alloyed with pyrites or other metallic ores, as "tin witts" fit for the calcining process.

Reverting to the contents of the long cistern in front of the mill, the central portion is delivered into a wooden trough immediately over the mineral, and washed by a small stream of water direct to the circular buddle, for undergoing the buddling process on a large scale, in a less expensive manner than the richer deposit. The lower division, or "tailings," of the cistern is lifted into a similar trough, and washed to other circular buddles, to undergo an additional washing over the central deposit. When brought to the required standard by repeated washings, with rejection of the worthless tailings, the richest ore is transferred to the rectangular buddle, and from thence through the tossing-tub, from whence it emerges as "tin witts," in the same manner as the richest division of the long cistern. The circular buddle is fully described and illustrated under the dressing of copper ores.

The contents of the slime-pit are delivered into the head of trunking-boxes, and subjected to the trunking process. The trunking-box consists of a long sloping cistern, with a division across its upper end, forming a small quadrangular cistern, in which the ore slime and water are delivered. A paddle slowly vibrates in the square cistern, which agitates the mixture, and at each stroke discharges a small quantity into the sloping trunk cistern. Here it is caused to flow evenly over the surface, depositing the heavier particles near the paddle, and the less valuable lower down. The process is continued till a sufficient depth of mineral has accumulated in the cistern, when the further admission of the mixture is prevented, and the quantity treated removed. The head, or superior portion of the trunk, is delivered to the "racking-tables;" the middle is again trunked, while the tailings are discharged as nearly worthless.

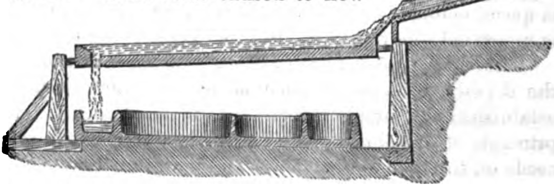


Fig. 150.

The racking-table (Fig. 150) consists of a wooden table, declining six inches in a length of nine feet, and furnished with shallow beveled flanches as a frame; at the bottom a narrow space intervenes between the table and flanch. It is supported on a frame-work or posts, two and a-half or three feet high, by centre pivots on which it freely turns. The head of the table receives the mixture of ore and water over a sloping board, leather-hinged, to admit of the table vibrating. Underneath, on the floor, the length of the table is divided into three by boxes or troughs.

In operating with the racking-table, the slimy ore, to the extent of twelve or fifteen pounds, is placed at the fixed head, and washed down over the hinge-board to the table. Here the attendant, with a solid rake or hard brush, distributes it equally over the head; the richest particles remain on the highest part of the table, by virtue of their greater specific gravity, the slimy water escaping through the narrow slit at the bottom into a gutter. When the charge of ore has been thoroughly racked, the table is turned on edge, and the deposit on its surface washed into the vessels underneath. The contents of these will vary in quality; the upper box may contain clean ore, but more frequently it is again racked, and then sent to the tossing-tub. The ore in the middle box will be washed once, and the lower box twice or three times, before going to the tossing process.

It is to be observed that in all the processes used in the dressing of tin ores, the distinguishing feature is the advantage taken of the great specific gravity (about 6·60) of the oxide of tin to effect its separation from other substances by subsidence in water. This is the principle pursued alike with stamps, cistern, buddle, trunk, tossing-tub, and racking-table. By stamping the ore to a fine powder, and suspending it in water, it is obvious that the

heavier particles will descend most rapidly, and be found collected at the bottom. Assuming that oxide of tin is the heaviest ingredient, its separation seems a very simple process: the particles subsiding first will naturally be richest in tin; but it is equally probable that in the superincumbent strata there yet remains a large proportion of the whole. With the exception of the top stratum, these are again washed, for the further separation of oxide. Yet, after passing and repassing through the several processes described, it is questionable if more than fifty per cent. of the tin oxide in the ore treated is recovered, the remaining fifty per cent. being lost.

This may appear a high estimate of loss; but on reviewing the whole of the dressing process, it must be evident that, though conducted on long-established and simple principles, a moiety, at least, of the tin is lost. The principle of dressing by subsidence in water is faulty, inasmuch as it proceeds on the assumption that after stamping, the oxide of tin exists as clean, independent grains, in a mixture consisting essentially of sand. In many mines the tin oxide is to the stony matter as 3 to 100. Now, looking at the manner in which the two are combined, we may conclude that while the stamping results in a number of particles of oxide of tin nearly free from gangue, a far greater number will consist of stony matter with a small alloy of tin. When subjected to the subsidence process, the great specific gravity of the former results in their immediate separation and collection, and the next heaviest particles will be similarly collected; but the largest quantity is discharged as worthless, because of its lightness, when, owing to its being in greater quantity, it is capable of abstracting a moiety of the tin oxide. While the defects of the present system of dressing tin ores are admitted by many intelligent miners, a remedy which shall enable a larger per-centage of the oxide to be recovered, is a desideratum which improvements in metallurgy alone can supply.

In very many instances, with great advantage, the stamps may be almost, if not entirely, substituted by the employment of the crusher, of precisely the same form as that described for the treatment of copper ores. The crushing is effected with much greater rapidity by the crusher than by the stamps, and at much less cost; but little attention has as yet been devoted to this subject, and it is curious to observe among tin-miners the strange notion they have that the crusher cannot do for tin stuff what it will do for copper stuff, although they may want precisely the same sort of effect to be produced. Much tin stuff consists principally of white, hard, and brittle quartz, interspersed with black oxide of tin in solid compact masses. The crusher produces a peculiarly desirable effect on such ores by cracking off the quartz from the tin, leaving the tin in large coarse grains, which, when the other earthy and metallic refuse matters have been dressed, are left extremely rich in the form known as "jigged tin." That which has been by the same operation crushed smaller is extracted as fluran, and the remainder separated as smalls and slimes. The crusher was first introduced at Drake Walls Mine, and its use has now been maintained for many years with great advantage. In other mines a large proportion of the tin oxide is in a very finely divided

state, disseminated throughout masses of indurated slate or capel; and the miner will commonly assert that the crusher cannot with such tin stuff be used with advantage. He is, however, mistaken; for with the proper use of a crusher suitably arranged, the work of the stamps can be more efficiently done, with greater rapidity, and at much less cost. This matter is of importance, not merely because the work is done at less cost, but that much tin stuff now rejected, because not rich enough to pay the cost of stamping, would otherwise be worked over with considerable advantage.

Greatly improved developments of tin mines are to be anticipated from the direction of greater attention to the use and proper management of the crushing mill.

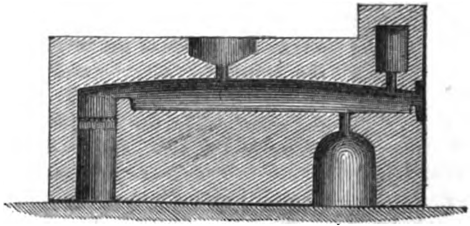


Fig. 151.

The oxide is frequently contaminated with copper pyrites, arsenic, and other substances. When this is the case the "tin witts" is subjected to a calcining process in a reverberatory furnace. Fig. 151 is a sectional elevation, and Fig. 152 a sectional plan of the furnace employed. The dimensions and form vary with different builders; but the general principle is the same in all burning-houses. The furnace is built of stone, lined throughout the interior with fire-brick, and furnished with a working-bottom of the same material. A narrow fire-place at one end communicates for its entire length with the rear end of the chamber of the furnace, which may be nine feet long, five feet wide in the middle, four feet at the rear, fourteen inches high, and twenty inches wide at the working-door. The flame from the grate is deflected on to the floor, and escapes through a flue over the working-door. The ore for calcination is placed in a cavity on the top of the furnace outside, from whence it is discharged, as required, into the chamber below. Under the floor is an arch, having a narrow connecting aperture with the interior, through which the calcined ore is drawn. The working-door is provided with a serrated bottom plate, to act as a series of fulcrums to a long rabble, employed in stirring and raking up the charge, so that all of it may receive the same thorough calcination. The thrust of the arch is met by a system of iron binding. A charge consists of ten or twelve hundredweights of tin ore, which may be the same number of hours burning, depending on the quantity and quality of the ore to be operated on. This

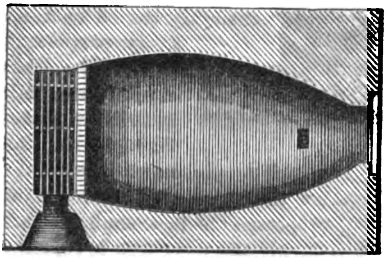


Fig. 152.

quantity of ore may be calcined with a consumption of two hundredweights of coal. A dull red-heat, while it has no injurious effect on the tin, volatilizes much of the arsenic and sulphur, and oxidizes the other metals so that specifically they become lighter than the tin oxide.

Instead of the ordinary reverberatory furnace, Brunton's calciner is now much used in tin mines, a sectional elevation of which is shown in Fig. 153. It is a circular cast-iron table, supported on a central stout iron shaft, suitably stepped in bearings, to allow of its being slowly revolved by the gearing of a toothed wheel fastened on the under side of the revolving bed C, which is placed under the dome of a reverberatory furnace, the fire-place A being on one side, and the flue B, leading to the main chimney, on the other. The ore is fed through a hopper, E, placed in the crown of the arch, and is distributed, and regularly turned over and thrust from the centre to the circumference, by the arrangement shown in the sectional elevation. The revolution of the bed of the furnace is effected by the attachment of the machinery to a small water-wheel. The ore having been constantly turned over, and every particle exposed to the oxidizing influence of the heated air passing through the furnace, when it has reached the discharging point H, it is there thrust out of the furnace into the wrinkle G, in a steady small stream, proportionate to a similar stream supplied through the hopper. The rate of supply and discharge is regulated by the rate of motion imparted to the revolving bed, which is determined by the amount of time required by the various ores subjected to calcination. It is evident that much less labour is necessary for the working of this, than of the ordinary reverberatory furnace; and a less consumption of fuel is also sufficient for the production of the same effect.

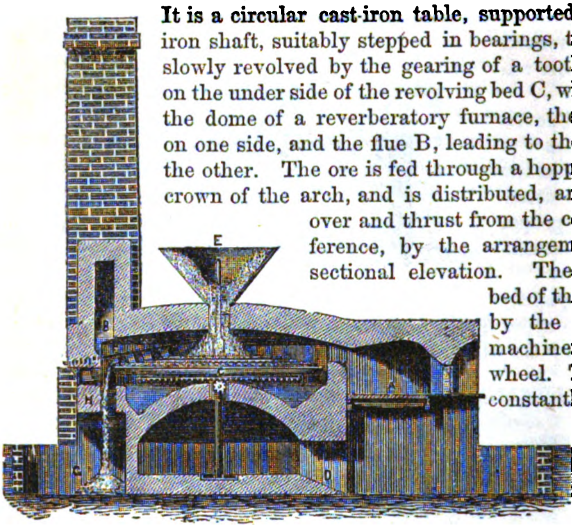


Fig. 153.

The flue from the calciners is commonly conducted a considerable distance up the side of a hill, to a short chimney-stack, or, better still, a large square tower filled with brush-wood or furze. For the first 100 or 150 feet from the furnace, the flue is built much larger than further off, with divisional walls to increase the length of circulation of the volatile products from the furnace; doorways are built in the sides of these chambers, and these are closed up with temporary brick-work, or with large stones. The arsenical fumes evolved are nearly all condensed in these chambers in the form of a white powder, which is the white arsenic or arsenious acid. At convenient intervals of a month to three months, the flues are opened, the crude arsenic

is removed, packed in casks, and sold to the arsenic manufacturer for refining. The sulphurous acid evolved with the arsenic passes on, and is discharged from the chimney into the surrounding atmosphere; not unfrequently during damp weather causing much damage to adjacent vegetation. This might be entirely avoided by the filling of the tower with coke, kept moist with a small stream of water, which would absorb and condense all the sulphurous acid.

Hitherto the process of calcination has, with but very few exceptions, been employed exclusively on dressed ores; but great advantage in many instances would be attainable by selecting those ores which contain sufficient iron, copper, or arsenical pyrites, to burn of themselves without fuel. The calcination in this case would be conducted in a furnace resembling a small lime-kiln, the ore being supplied at the top; and when burnt out, drawn at the bottom into the ash-pit below the fire-bars, in which water is kept, so that, by the hot burnt ore dropping into it, and being suddenly chilled, it falls to pieces. The ore thus burnt is much easier for reduction to powder by either the crusher or the stamps; indeed, its condition would be such that the crusher alone might be employed, without the aid of stamps, for reducing even to the finest powder. From the side of the top of the furnace the volatile product may be led off to the main flue, with which the reverberatory furnace communicates. The partially calcined ore having been dressed in the usual manner for witts, the final calcination may be effected in the reverberatory furnace, as already described.

From the "wrinkle" of the calcining furnace, the burnt ore is removed to the burning-house floors, where it is subjected to a series of washing processes, much more carefully conducted than those employed in the preparation of the tin witts. The witts having been burned in separate parcels according to their size, as jigged, fluran, smalls or "smales," slime, and rough or "rows," they are operated on accordingly; the jigged being simply jigged over again in a copper sieve; the fluran passed through the buddle and tie; and the smaller sizes through a very much more complicated process, consisting first of washing carefully in the buddle, whence it is sized out according to the part of the buddle in which it settles; then of tossing or "tozing," and packing in a kieve, again washing on a hair-sieve in another kieve or "dillcughing," so as to throw off the light waste into the water, leaving the crop tin on the sieve, whence it is thrown into hand-barrows, and conveyed to the hutches, where it is stored, until sampling time, under lock. If the tin witts should have been "corrupted" with a "bad brood or mixture," such as mundic or iron pyrites, copper pyrites, arsenic, mock lead, or the sulphuret of molybdenum, wolfram, &c., the various operations described, lead to the production of a great number of temporarily refuse matters, which are treated over again according to the exact process indicated by the examination of a dressing captain, who forms his opinion from "vanning" samples of the respective heaps. The vanning consists in taking a small sample on a large, thin, light shovel, known as the vanning shovel, and with a peculiar motion scarcely describable, washing it in water, so as

to separate the waste, throwing it back by a streaming of water towards the handle or back part of the shovel, and leaving the superior tin stuff forward at the tip. The process appears, from the dexterity of the manipulator, to be exceedingly easy; but it requires much practice to attain even moderate success in thus effecting the separation of the tin stuff. After all has been done that can be effected by the operations described, the refuse, known as "burnt leavings," is usually sent to the stamps, to be stamped over again, with some siliceous stones or "craze." By stamping, the burnt tin stuff is crushed much finer; and so, by washing, the earthy matters are separated, which before, by adhering to the oxide of tin, made it too light to allow of its separating out by settling.

The month's sampling from each mine usually consists of at least two or three different qualities, depending principally upon the extent to which the impurities have been separated by the various dressing operations. The lowest quality, known as roughs, or rows, is of very inferior quality, in spite even of treatment with acids. This is usually occasioned by the presence of much metallic iron derived from the tools in underground working, and from small fragments of the machinery through which the ore has passed. At Drake Walls Mine, this quality obtained scarcely more than one-half of the price of the better sorts, although the quantity of iron present was not more than about 20 per cent. By the employment of a boy, at a cost of sixpence per day, to pick over the ore with a horse-shoe magnet, the weight of the parcel is reduced by one-fifth; but its value has been doubled, and this sort has disappeared from the samplings, the clean ore being mixed away with the best quality.

Until a very recent period, the notion prevailed amongst tin-dressers that the metal, or "white tin," obtainable from the ore raised in mines, or "mine-tin," was entirely different from the metal extracted from the ore found in stream-works, or stream-tin, and that it was impossible to obtain "grain-tin," the purest commercial tin, from any ore but the stream-tin; the mine-tin producing only common tin. This was because after the tin ore from the mines had been passed through all the dressing processes before described, in strictest accordance with the prescribed rules of tin-dressing, yet such traces of foreign metallic matters, especially of copper and of iron, were still left in combination with the black tin, that the smelting processes employed for the reduction of the metal would cause the formation of alloys of tin with these metals; and such is the effect of the combination of only very small proportions of these metals, that the quality of the white tin could never be brought up equal to the metal from the stream-tin.

As the native black oxide of tin, or "black tin," is so very indifferent to the action of acids, the treatment of it chemically with acids, for the separation of foreign metallic oxides, is of peculiar facility. With moderate care, mine-tin may be made equal in quality for the production of metal to stream-tin; and supposing no unfair interposition on the part of the smelters, such as has been from time to time attempted on their part, to prevent the introduction of improved processes for treatment, considerable advantage must

accrue to the mine, from making it a rule to render the black tin pure before it is sold.

About 1842, at Balleswidden Mine, in Cornwall, acids were first employed by Duclos in the treatment of tin ores. In the same year a patent was obtained by W. Longmaid (sealed October 20th, 1842), having for its object the utilization of the sulphur in all sulphur ores, by mixing with them common salt, and roasting the mixture, so converting the sulphur into sulphate of soda, the copper into a chloride. Both these substances being soluble in water, they are washed off, leaving the peroxide of iron, the oxide of tin, and earthy matters, from which they could easily be separated by washing. Where the foreign matters consist almost exclusively of oxide of iron, muriatic acid is employed with greatest advantage, the use of which was patented long after its employment elsewhere, by Mitchell, April 11th, 1843. Where the tin stuff, after calcination, still contains copper, sulphuric acid is employed with the greatest advantage; the sulphate of copper produced being washed off, and the copper precipitated in the metallic state with iron, or, preferably, in the state of oxide with soda ash.

Where the tin stuff has been found associated with much wolfram, as at Drake Walls, in consequence of its specific gravity being so nearly the same as that of tin oxide, wolfram being 7·1 to 7·4, and tin oxide 6·3 to 7·0, it was found impossible, by the ordinary processes of dressing and calcining, to separate them; and for very many years, in consequence, the price paid by the smelters for the ores from Drake Walls Mine was lower than that of any other mine in Cornwall. Since the introduction of Oxland's process for treating these ores, they have been so improved in quality that they are now used for the production of grain-tin, and fetch the highest price. The process consists in taking the ore dressed as perfectly as possible in the ordinary manner; and having ascertained the proportion of wolfram in it, then mixing with the ore such a proportion of soda ash or crude soda as will provide an equivalent of soda for the tungstic acid of the wolfram present. The mixture is then put into the furnace, and there roasted at a low red-heat, until a combination is effected between the tungstic acid and the soda. The iron with which the acid had been previously in combination is at the same time converted into a peroxide, and rendered sufficiently light to be washed off with facility. When the roasting is completed—which may be known by the change of colour, and by the mass assuming a slightly pasty condition—the charge is drawn through a hole in the bed of the furnace into the arch or "wrinkle" beneath. A fresh charge is introduced through the hole in the crown of the furnace from the "dry;" and as soon as the charge is spread over the bed, the furnace is shut, the fire made up, and it is left without further stirring, until the surface of the charge assumes the appearance of becoming moist, with a slight hissing or frizzing sound. In the meantime the charge, while still red-hot in the interior, is removed from the "wrinkle" and thrown into a cistern of water. The water thus heated dissolves the tungstate of soda; the solution is run off from a hole in the bottom, provided with a suitable filter, to prevent the running out of the tin ore. Fresh water

is again run on, to wash off the remainder of the soluble matters; and the tin stuff is then removed from the tank to the burning-house dressing-floor for final treatment. The strong solution is evaporated in iron pans to the crystallizing point, when it is drawn off into coolers. After a few days a large crop of beautifully crystallized tungstate of soda is obtained; and the mother liquor is again treated in a similar manner, for the obtaining of a further quantity of crystals. The washings of the tin stuff run off from the tank are used instead of plain water for the lixiviation of fresh charges from the furnace.

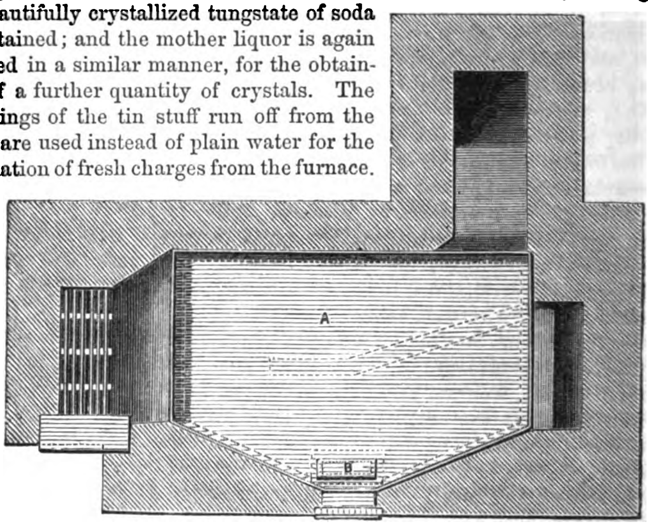


Fig. 154.

Instead of soda ash, sulphate of soda may be employed, which does not cost half as much as the former; but the operation requires to be conducted with care, such only as would be taken by ordinary workmen, under the direct active supervision of a person understanding the nature of the process.

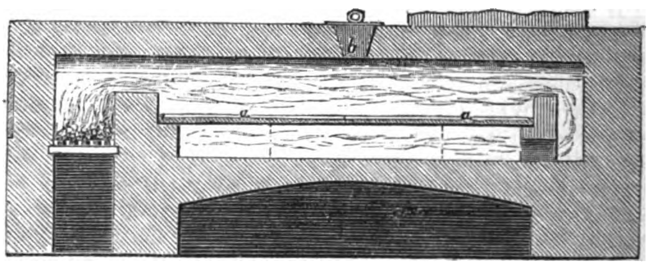


Fig. 155.

With the tin stuff a quantity of crude sulphate of soda or salt-cake is mixed, such as will contain a full equivalent of soda for the tungstic acid present; but it is necessary also, at the same time, to mix with the salt-cake a quantity of powdered coal or culm, sufficient for the decomposition of the sulphuric

acid, and consequent evolution of the sulphur. The charge having been well mixed in proper proportions, is thrown into the furnace, the doors closed, and the charge heated to a dull red throughout, with a strong smoky or reducing flame, the object being at first to effect the deoxidation of sulphuric acid. It should be well stirred, and the reducing flame maintained until the pyrophoric appearance has ceased. A bright clear flame should then be produced, carrying with it much highly heated, but undecomposed atmospheric air, constituting an oxidating flame, as the object now is to cause the combination of the tungstic acid of the wolfram with the soda, from which the sulphur has been sufficiently detached, to allow the tungstic acid to complete the decomposition. A moderately clever furnace-man will produce the effect desired with great nicety.

The furnace is of peculiar construction, as shown in Figs. 154 and 155; it will be seen that the fire passes over a cast-iron bed, provided with a rim rising four inches around the sides. The bed is cast in two equal parts; this construction was found necessary, as the plate, if cast in one piece, always cracked through the middle. The bed is set on the sides of the furnace, but with a diagonal line of brick-work running underneath from the back nearly to the front, forming a flue, through which the flame and smoke circulate, instead of, as in ordinary reverberatory furnaces, passing directly away to the main flue of the chimney; thus a great economy of fuel is effected, without, as might have been expected, great cost for the maintenance of condition of the iron bed. Although in the intervals of the employment of the furnace for carrying on the wolfram process, it is employed for calcining the sulphurous and arsenical witts; yet one of these beds has been maintained in working condition, without requiring renewal, for nearly three years. Iron was chosen as the material for the bed of the furnace, not merely on account of the economy of fuel involved, but principally because the ordinary fire-brick is entirely unsuited for the successful prosecution of the process. Silica and tin have a great affinity for each other; and this is very materially promoted by the intervention of any alkaline matter, so that with fire-brick much soda-silicate of tin would have been produced at the expense of leaving much of the tungstates still unacted on. This process has now been at work since 1850 continuously, in Drake Walls Mine, with considerable pecuniary advantage to the adventurers.

Since the invention of this process, a plan has been introduced by Young of Manchester for the production of stannate of soda for dyeing purposes, by the calcination of a mixture of soda and of the smalls or slime of tin oxide.

The dressing of the tin ore having been completed, towards the end of the month's working, samples are taken of the ores in their various conditions, and these are sent to the various smelting establishments in different parts of Cornwall.

After these have been assayed by the smelters, they send offers of prices according to their value, having such a relation to the price of the metal obtainable as they are pleased to give, but not such as they are really worth.

The ores having at length found their way from the mine to the smelting-house, have here but few processes to pass through. Occasionally, as they may require, they are digested in sulphuric or muriatic acid, to remove any residuary iron or copper. In this country the extraction of the metal is effected in a reverberatory furnace, as shown in sectional elevation, Fig. 156, and in plan, Fig. 157, where A is the fire-door for cleaning the fire-bars; E the draught-hole, sometimes opened during the skimming of the charge; F is a bed of fire-brick, supported on an arch, or on iron bars; B is the door for charging; and C the door for working the charge, which is placed at the back, under the chimney, for the purpose of preventing the oxidating effect of the stream of air which would obtain access to the charge, if, as is usually the case with reverberatory furnaces, the working-door were in the side. G G are iron pans, with fire beneath them, into which the charge is run, when melted, through the tap-hole D. The chimney is usually 40 to 50 feet in height. The ores, as rendered to the smelter, vary in quality from 12 to 15 in 20 for white tin, or from 60 to 75 per cent.; but the assays are always spoken of in the proportions of 20. For the ordinary size furnace, the charge consists of 20 to 25 cwt. of black tin, mixed with 12 to 18 per cent. of powdered culm or anthracite, and a small quantity of slaked lime or fluor-spar, varied according to the proportion of silica contained in the ore. The materials are damped, well mixed, and thrown into the furnace through the door B, which is immediately closed, and the fire maintained as strongly as possible for six to eight hours, or until the whole mass is fused. The charge is then well mixed up, to ensure the complete fusion of any ore remaining unreduced. The doors are again closed for a short time, to recover the heat of the furnace, and to complete the fusion of the charge. It is again opened, and the

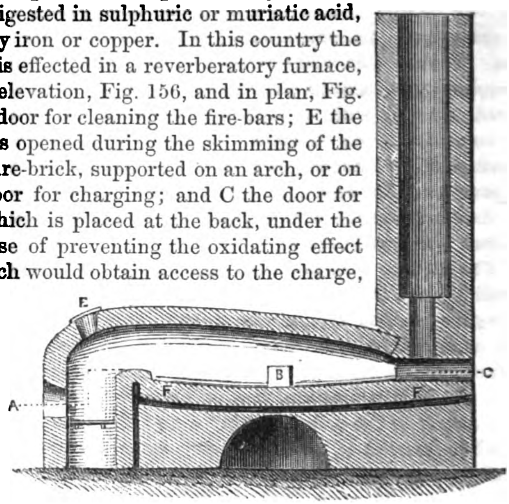


Fig. 156.

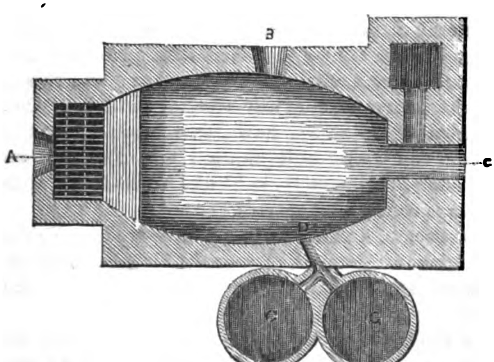


Fig. 157.

charge worked off, by first, through the door D, raking off the top scoria, which has been chilled by throwing a small quantity of damp small coal over the surface of the charge. About three-fourths of the whole of the scoria is raked off, and kept separate from the remainder, as being fit only to be thrown away; a portion of the remainder is removed, and set aside for stamping over again, to separate the "prills" of metal diffused through the slag; the last portion removed from the surface of the clean tin is reserved for melting over again. The metal itself is run out into the cast-iron pans G, through the hole D, by clearing out the stopper of fire-clay with which the mouth of G was closed. Here it is allowed to stand for some time, until the scoria in the body of the metal has risen to the surface. After skimming, the metal is ladled out into cast-iron moulds, which contain about three cwt. each. One day a week is usually devoted to the refining of the crude metal obtained in this first process. From the following analyses by Berthier of crude tins, it will be seen what has to be accomplished by the refining operation, or by the treatment of the product of the first process.

	1.	2.	3.	4.	5.
Tin . .	99·5	73·0	97·0	95·0	82·5
Iron . .	trace	14·5	2·8	1·2	16·5
Lead . .	·2	9·9	..	3·0	·5
	99·7	97·4	99·8	99·2	99·5

The refining operation involves two processes: the first, a liquation; the second, a boiling or tossing of the metal.

The same reverberatory furnace may be employed for the liquation, as for the reducing operation. The furnace is charged with blocks of the crude metal piled up hollow, so as to allow of the flame passing through the pile: a moderate heat being employed, the tin is sweated out; and as it flows down, it is allowed to run out into one of the pans G, which has been heated by a fire beneath, in readiness to receive it. The mass gradually crumbles down; and as room is made, more blocks are put into the furnace, until about five to six tons have been accumulated in the pan. The crumbled mass of residuary matters left in the furnace is either at once removed from the furnace; or, by raising the heat of the furnace, it is fused and run into the adjacent pot, to be removed for fresh treatment with the prills from the stamped scoria, and the last skimmings of the metal in the original reducing process. The constitution of this alloy is shown in the foregoing table under Column 5; it contains about two atoms of tin for one atom of iron. Column 2 shows the constitution of the last product of the liquation, which is obtained by an increase of heat; it is grayish-white, very hard; capable of being laminated; slightly flexible; very magnetic. Column 3 is the product of the fusion of the scoria obtained in the reducing operation: it is also very magnetic. Column 4 is the alloy obtained by the fusion in the blast furnace of the infusible residue of the liquation in the reverberatory furnace. On referring to Column 2, it will be seen that nearly all the lead contained in the crude metal subjected to liquation is retained in the mass until after most of

the tin has been melted out, as may be seen by comparing Column 2 with Column 1, which is the first product of liquation at the lower heat. The first residuary products of liquation are fused with a stronger heat, cast into moulds, and subjected to a second liquation: the final residue requires a very much stronger heat for fusion. The product known as "hard heads" resembles cast-iron, highly crystallized, white, very brittle, and easily reduced to powder. Berthier's analysis shows its composition to be—

Tin	36·2
Iron	55·6
Arsenic . . .	·6
Cobalt	4·0
	96·4

The scoria also, according to Berthier, consists of—

Silica	34·4
Protoxide of tin . .	27·4
Protoxide of iron .	17·6
Protoxide of manganese .	3·6
Protoxide of tungsten .	2·0
Lime	1·2
Magnesia . . .	2·4
Alumina . . .	10·0
	98·6

The eliquated metal having been accumulated in sufficient quantity in the iron pan, the process of refining is commenced by forcing under the surface of the metal, the bundle of billets of green wood shown mounted in the crane, by the side of the furnace, over the pan in Fig. 158. The steam and gases evolved from the wood, cause a violent ebullition, and the production of a frothy scum, containing oxide of tin, which is skimmed off, and set aside for further treatment, with the scoria produced in the first operations. Instead of boiling with green wood, the same effect is sometimes produced by tossing or raising the metal in ladles, and pouring, from some height through the air, back again into the pan. When sufficiently boiled or tossed, and skimmed, which process occupies about three hours, the metal is allowed to stand undisturbed for another hour, during which time it settles into three parts or zones, of which the top is the purest, the middle the next in quality, and the lowest the most impure. The heat of the metal is maintained while in the pan by a fire underneath. When it has stood quiet sufficiently long, the metal is carefully skimmed, and then ladled out into iron moulds, which contain about three hundredweights.

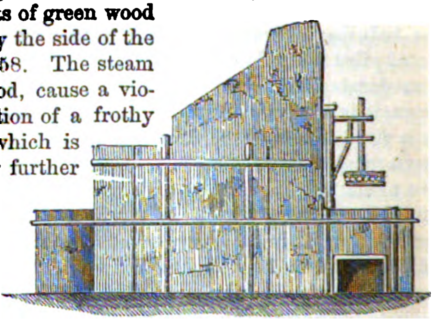


Fig. 158.

The three different sorts are kept separate, their quality being ascertained by taking a small ladleful, stirring and skimming it until sufficiently cold, and then pouring it into a stone ingot-mould, watching the appearance of the metal as it cools. If sufficiently pure to class as grain-tin, it will remain bright and clear, full, and well rounded on the sides, until quite cold; if only sufficiently good to class as common tin, it will remain bright, but not so full and well rounded on the sides; until, at the instant of becoming solid, from the middle of the ingot a frosted crystalline appearance shoots out to the sides. In the third quality, the colour becomes slightly yellowish, and the appearance of the frosted crystalline markings takes place sooner, and completely covers the whole of the surface. Examining the ingots when quite cold, by bending them, the remarkable crackling sound characteristic of tin is much greater in proportion as it is purer.

The two first qualities are reserved for the market; the third is again subjected to liquation. The best grain-tin is quite pure; but the composition of the other three qualities is shown in the annexed analyses by Berthier:—

	Ordinary.	Common.	Bad.
Tin	99·76	98·64	95·00
Copper	·24	1·16	3·00
Lead	....	·20	1·50
Iron.	a trace	a trace	....
Arsenic	a trace	a trace	a trace
	100·00	100·00	99·50

Formerly, in Cornwall, where nearly all the tin-smelting is carried on, the ores were smelted in blast-furnaces—and hence the smelting establishments were known as blowing-houses: at present, reverberatory furnaces only are employed; but in Germany, at Altenberg, the blast-furnace is still employed, as shown in Figs. 159 and 160, which are a vertical section and plan of the furnace, with the bellows employed for producing the blast. A is the plan of the large furnace employed for the fusion of the raw ore, being about fourteen feet high, constructed in the body, J J, of coarse-grained porphyritic syenite. The laboratory, or crucible of the furnace, F, is built of a very refractory fire-brick; it is of an oval form, and the lower portion of it is lined with a very stiff brasque of charcoal and fire-clay, tightly rammed down. From the bottom of the furnace a channel, shown in the elevation, conducts the fused charge into the iron basin, I, from which the scoria is let off from the side down the inclined plane, G, into the small reservoir of water, H; and the metal beneath is let out by the channel, K, into the receiver, L, which is of a rectangular form, about eighteen inches square and two feet deep. The large furnace stands under a dome, or cupola, shown

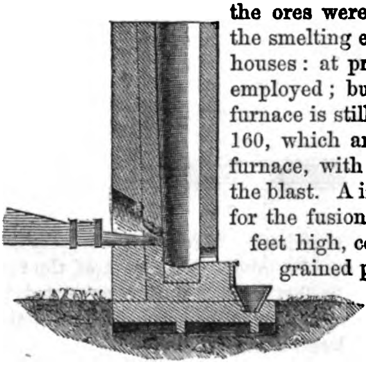


Fig. 159.

by the dotted line around the furnace; it is twenty feet long, twelve wide, and sixteen high, above the top of the furnace. It is so constructed as to catch the light powder of the ore driven off by the blast, so as to prevent its waste. The blast is produced by the bellows, D D, driven by the cog-wheel

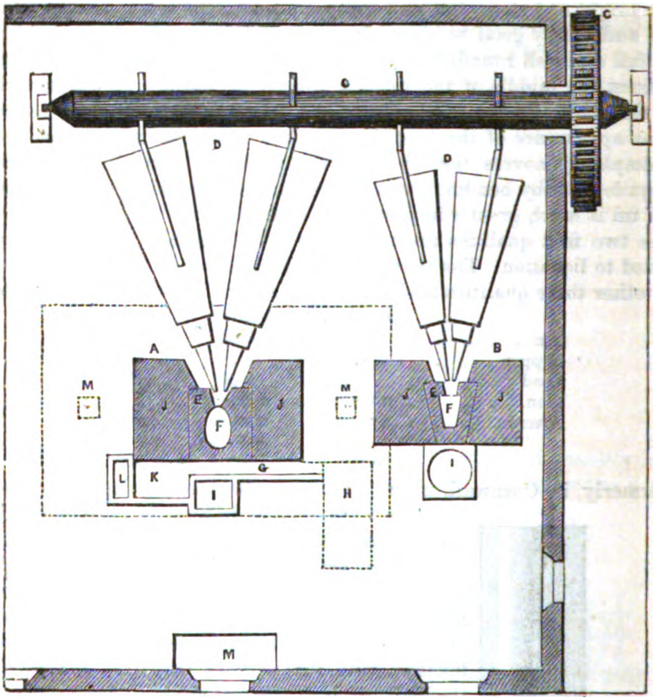


Fig. 160.

on the shaft, C, which is moved by a water-wheel. The furnace is charged through a door on the left side, about three feet above the hearth of the furnace. The small furnace, B, is about five feet high. It is constructed in the same manner as the high furnace, but is used only for the fusion of the scoria arising from the operations in the large furnace.

The furnaces are slowly dried before they are used. When the large furnace is first set to work, it is charged with scoria and fuel; the blast is set on moderately at first, so as to reduce the most fusible portion of the scoria, before the remainder is brought into fusion; afterwards the heat is increased until the furnace is brought into fit condition for regularly working off the raw ore, which is then charged; and at the end of four hours the metal begins to make its appearance. As the scoria appears on the surface of the basin in the bottom of the furnace, it is skimmed off; until at the end of about

twenty to twenty four hours, the basin is full of metal, when the hole is opened, and the metal run out into the front basin. From time to time, according to the appearance of the furnace, especially having regard to the condition of the tuyères of scoria formed in front of the nozzles of the bellows, fresh charges of ore are added in varying quantities.

Although the metal produced from the blast furnace is usually better than that obtained from the reverberatory furnace, yet the expense of fuel and the loss of ore are so much greater than with the latter, that the use of the blast furnace is nearly abandoned. With the reverberatory furnace, for one ton of tin produced, the consumption of fuel amounts to 1¾ tons, with a loss of five per cent. of metal. With the blast furnace the fuel consumed amounts to about three tons of coals, with a loss of metal equal to fifteen per cent.

From the smelting-house the metal is sent to market, in the form of blocks of three hundredweights, one hundredweight, or half a hundredweight each; or in strips, cast in moulds of white marble, about two feet long, one inch wide, and half an inch thick; or it is rendered in the form known as "grain-tin," which is made by heating a block to as high a temperature as possible, without melting. On letting the block so heated fall from a considerable height, or by striking it with a heavy hammer, it is shivered into fragments, presenting the appearance of long crystalline fibrous masses, entangled in each other, in forms scarcely describable.

The metal is largely employed in the manufacture of various alloys; those of tin with copper have already been noticed under "Copper." For the manufacture of solders it is much used in the following proportions:—

	Tin.	Lead.
Plumber's solder	1	1
Tinman's solder	1	2
Pewterer's solder	2	1

It is not much used in the pure metallic form, but almost exclusively as a tin-foil, for covering bodies to protect them more effectually from moisture than paper will do; or for the making of the amalgam which is used in the manufacture of looking-glasses. Perhaps the most extensive use of the metal is for making tin-plate, which is not, as is commonly supposed, a plate of tin, but a plate of sheet-iron, the surfaces of which are covered with an alloy of iron with tin. Two different sorts of sheet-iron are used for the manufacture of the plates—"coke" and "charcoal" iron; so called, according as the one or the other fuel is employed in the manufacture of the sheet-iron. Although much manual dexterity is necessary for the making of tin-plates, yet the process itself is simple. The plates of iron, cut by machinery to the proper size, are pickled; that is, laid in dilute sulphuric acid for a sufficient time to clear the scale of oxide from the surfaces of the sheets. They are carefully washed clean, and kept in store until wanted, under pure water. The plates, dried by rubbing them over with warm bran, are put into a bath of melted tin, covered with tallow. They are kept in this bath about an hour and a half, are removed, and dipped one by one into another bath of purer tin for a moment; they are passed on, to be dipped into a bath of tallow; thence they are

removed to a rack and are set on edge until sufficiently cool for handling; and, finally, the wire formed at the lower edge by the metal running down over the surface, is removed by dipping the edge of the sheet into another bath of metal, only a quarter of an inch deep. When the wire is melted, the superfluous metal is removed by a sharp blow on the edge with a light stick. The tallow is then removed by cleaning with bran, and the plate is rendered fit for the market. Very large quantities of tin plate are used for the manufacture of domestic utensils, and in America for covering the roofs of houses.

Iron, either wrought or cast, may be easily tinned by first brightening it, either by filing or by laying it in sulphuric acid, washing it clean, then dipping it into a solution of "butter of zinc," or zinc dissolved in muriatic acid, drying the iron so dipped without wiping, and then dipping the iron for a few moments, or until it has reached the same temperature, into a bath of tin. Iron so tinned can be jointed to other soft metals with common tin solder.

Much of the grain-tin is used for the manufacture of dyers' mordants, known as "tin liquors," which are prepared in a variety of ways, according to the purposes for which they are required. They are, however, principally solutions of tin in muriatic acid, or nitro-muriatic acid, or of muriates or nitro-muriates in ammonia.

The quantity of tin ore raised in Cornwall in 1855, from 129 mines, amounted to 8415 tons; value, £541,643. In Devonshire, from 14 mines, 181 tons; value, £10,874. In the same year, the importations of metallic tin into the United Kingdom amounted to 1612 tons, and the exportations to 1338 tons; value, £152,928.

CHAPTER XXIX.

ZINC, ITS ALLOYS AND SYNONYMES.

Synonymes: Zincum; Zinc., *Fr.*; Zink, *Ger.*; Spelter, Conterfey.—Frisch, a German writer, says that it was first called zink, zinetum, or zincum, because the furnace-calamine assumes the figure of zinken or zachen, nails or spikes. This metal was unknown to the ancients; and although partially described by the alchemist Albertus Magnus, in the thirteenth century, and mentioned by Grignon as having been found in the ruins of an ancient Roman city in Champagne, we have no distinct mention of the metal until Paracelsus, in the sixteenth century, first used its name, and gave a precise description of it. Henkel, in 1741, gave an account of his success in obtaining the metal from calamine, by the addition of a carbonaceous material; and he is, no doubt, the first who procured the metal from calamine, at least in Europe. Dr. Isaac Lawson, of Scotland, first introduced the manufacture of zinc on the large scale into Great Britain. Zinc works were established at Bristol by Champion in 1743. At a remote period, the ores of zinc, known as cadmia and tutia, were used with copper in the manufacture of brass.

The metal was first introduced into Europe from the East Indies, under the names of speltrum, speauter, Indian tin. The present process employed in England for the smelting of the metal, *per descensum*, appears to have been introduced from China about the year 1740. In Beckman's "History of Inventions," and Watson's "Chemical Essays," are to be found interesting historical memoirs of the discovery and introduction of this metal. From the former of these writers, we select a few extracts illustrating the discovery of this metal.

That the mixture of zinc and copper, known as brass, pinchbeck, prince's metal, &c., was known to the ancients, is beyond dispute. Mines containing the ores from which this yellow metal was produced, were held in high estimation, and much regretted when exhausted. In the course of time it was remarked that an ore, which must have been calamine, when added to copper while melting, gave it a yellow colour. This ore was therefore used, though it was not known what metal it contained, in the same manner as oxide of cobalt was employed in colouring glass. When, in course of time, more calamine was discovered, the ancient method of procuring brass from copper-ore containing zinc was abandoned; and it was found more convenient first to extract from it pure copper, and then to convert it into brass by the addition of calamine.

The ore known to the ancients as *cadmia*, was what the German's call *ofenbruck*, and which is with us called furnace-calamine, or what in melting ore containing zinc, or in making brass, falls to the bottom of the furnace.

For many centuries the furnace-calamine was thrown aside as useless; till at length, in the middle of the sixteenth century, Erasmus Ebenir first showed that it might be used instead of native calamine for making brass. This discovery induced the managers of the brass-works in the Hartz Forest to pick up carefully that which had previously been thrown aside as waste.

This metal is of a bluish-white colour, sufficiently hard to bear a polish. Its specific gravity is 6·8 to 7·2. It fuses at a low red-heat, and volatilizes at a white-heat, and distils over in close vessels; but in the open air, at a bright red, it takes fire, and burns away rapidly, with the production of dense fumes of white oxide of zinc, known as "philosopher's wool." Very fine turnings of the metal placed in an open wire-work basket, freely exposing it to the atmosphere, will take fire, and burn with great vivacity, giving out an intense light, if only set fire to with a lighted match. If the metal be cast into a thick cake, and allowed to cool very slowly, on breaking it the fracture will present a highly crystalline appearance. It is malleable in the cold, but brittle. Its greatest ductility and malleability are developed at temperatures between 212° and 220° Fah. Above these temperatures the metal becomes so very brittle that it can be reduced to powder. As it will not bear violent hammering when cold, so as to reduce it into thin sheets, it was not until a comparatively recent period, when its maximum ductility at the temperatures referred to was discovered, that the metal was used in the form of sheets or foils. By using a boiling solution of salt and water, the lamination of the metal can now be effected with ease; and its consumption has consequently very much increased. Drawn into a wire one-twelfth of an inch in diameter, it will support twenty-five pounds weight without breaking. It has a great affinity for oxygen. In a dry atmosphere, at ordinary temperatures, it remains unchanged; but in a moist atmosphere it rapidly tarnishes, and becomes covered with a very thin coating of white oxide. It decomposes water at a red-heat: it is very soluble in acids. In sulphuric acid, or oil of vitriol, it dissolves with the evolution of sulphurous acid; but in dilute sulphuric acid, as well as in muriatic acid, it dissolves with the evolution of hydrogen. The rapidity of solution is in the inverse ratio of its purity. Pure zinc requires eight days for its solution in the same quantity and same strength of acid in which the zinc of commerce is dissolved in an hour.

De la Rive has shown, by direct experiment, that zinc mixed with other metals, in the proportion of nine of the former to one of the latter, by solution in dilute sulphuric acid, produces the quantities of gas in a given time indicated in the following table:—

Zinc of commerce, and alloys of zinc, with iron in proportions as small as $\frac{2}{100}$ of iron	100
Alloys of zinc and copper	43
Do. of zinc and lead	15
Do. of zinc and tin	12
Distilled zinc	5

A rapid disengagement of gas may also be produced by surrounding the zinc with a spiral of platina wire. The best proportions of acid and water

appear to be not less than one of acid to three of water, and not more than one of acid to two of water. The zinc of commerce is never pure; it always contains traces of iron, carbon, arsenic, copper, lead, and cadmium. Zinc containing arsenic, on solution in either muriatic or sulphuric acid, evolves arseniuretted hydrogen. It may be purified by redistillation. It is also rapidly oxidized by the action of caustic potash and soda in water, entering as an acid into combination with these bases, forming soluble zincates of potash and soda. If metallic iron be present, and in contact with the zinc in the alkaline solution, hydrogen is given off as the salt is formed. The solution by evaporation is converted into a bright solid form, which is very deliquescent in the open air.

Zinc is never found native in the metallic state, but mineralized principally with oxygen, carbonic acid, sulphur, and silicic acid. The red oxide of zinc, brucite, or spartalite, is found in considerable quantities at Sparta, New Jersey, United States. It is of a blood-red colour, opaque, hard, and brittle. Its fracture is shining, lamellar, slightly conchoidal, and thin fragments are translucent. Specific gravity, 5·43. By exposure to the air, the surface becomes white, from the formation of a carbonate. Its composition, according to Berthier, is—

Oxide of zinc	88·00
Oxide of manganese	12·00
	100·00

A large mass of this mineral was exhibited by the New Jersey Mining Company in the Great Exhibition of 1851.

Carbonate of Zinc, Calamine, Zinc-spar, Rhombohedral Zinc Baryte, or *Smithsonite*, is found in the Mendip Hills, Somersetshire; Derbyshire, Cumberland; Leadhills and Wanlock-head, Scotland; Aix-la-Chapelle, Siberia, Hungary, Silesia, Brillon in Westphalia; Jefferson county, Missouri, U.S.; Mexico, and China. This mineral is quarried in very large quantities at Vieille Montagne, between Liege and Aix-la-Chapelle. It is found either white, yellowish-gray, or brown; mostly opaque, but occasionally translucent. It is of a granular texture; vitreous, pearly lustre; its fracture smooth, or imperfectly conchoidal. Specific gravity, 4·2 to 4·5. It is rarely found crystallized, but mostly in stalactitic cellular or botryoidal masses, or in radiated and lamellar concretions. It does not contain water. Its composition varies according to the localities whence it is obtained. The following analyses, given by Berthier, will show this:—

	Wales.	Siberia.	Ural.	Pyrenees.
Oxide of zinc	64·600	62·200	56·400	58·600
Protoxide of iron	..	·900	3·400	..
Protoxide of manganese	..	1·900	..	..
Carbonic acid and water	35·400	35·000	34·200	29·600
Earthy matters	..	..	·400	3·600
Peroxide of iron	..	..	5·000	5·000
Oxide of lead	..	..	..	2·600
	100·000	100·000	99·400	99·400

These may be stated as follow:—

	Wales.	Siberia.	Ural.	Pyrenees.
Carbonate of zinc	100·000	95·000	87·300	87·000
Carbonate of iron	..	1·500	5·300	3·200
Carbonate of manganese . .	..	3·	..	..
Hydrate of iron	..	..	5·300	5·600
Earthy matters	..	..	·400	3·600
	100·000	99·500	98·300	99·400

It is soluble in muriatic acid, with the evolution of carbonic acid gas; also in ammonia, and more rapidly in solution of carbonate of ammonia slightly heated.

The Silicate of Zinc, Electric Calamine, Siliceous Oxide of Zinc, Galmei, Prismatic Zinc Baryte, Willemite.—This mineral is found in large quantities in the same localities as the carbonate. It occurs massive, botryoidal, cellular, stalactitic, stalagmitic, but rarely crystallized, of a granular, fibrous, and lamellar structure. When heated, it becomes strongly electric; when pure it is colourless; but is mostly found of a bluish-white or yellow-gray. When crystallized it is transparent or translucent. Its fracture is compact or radiated, of a vitreous lustre. Its specific gravity is 3·379 to 3·434. It gelatinizes by solution in acids, in consequence of the presence of silica. It is not reducible alone with charcoal, but requires an earthy body or an alkali to detach the silica from the zinc oxide. When pure, it is a hydrated silicate of zinc, composed of two atoms of silicate of zinc and one atom of water. Berthier's analyses of three different samples are as follow:—

	Siberia.	Vieille Montagne.	Vieille Montagne.
Oxide of zinc	64·700	66·300	5·400
Silica	25·300	24·900	2·000
Water	9·500	7·400	·600
Oxide of copper . .	·500	..	..
Oxide of manganese .	..	..	..
Oxide of zinc	..	..	..
Oxide of iron	..	..	3·000
Oxide of tin	..	·300	..
Carbonate of zinc . .	..	1·100	89·000
	100·000	100·000	100·000

The silicate of zinc is also met with, occasionally in large masses, in the anhydrous state: it is known as Williamsite. It is found in Switzerland, in the same localities as the calamines, and associated with them; its constitution being the same, excepting the water.

Sulphuret of Zinc Blende, Black-jack.—This is a mineral of zinc, which, as some of the principal sources of calamine are becoming exhausted, is increasing in importance as an ore of this metal. It is found in large quantities in the Isle of Man, Cumberland, Derbyshire, Cornwall, the Hartz, Hungary, Transylvania, Saxony, Bohemia, Sweden, and in the United States. The produce of the British mines for the year 1855, amounted to about 10,000 tons.

It is very seldom found in large quantities alone; but is more commonly

associated with the sulphur ores of lead, or with iron or copper pyrites. Small quantities of cadmium are commonly associated with blende. It is found in crystals of the dodecahedral form, massive, crystalline; brilliant, glassy, or resinous lustre, and texture rarely granular; transparent, light yellow-green, red-brown, or black, and opaque. Specific gravity, 3·945 to 4·107. It is phosphorescent with heat and friction, and decrepitates when heated. It is soluble in nitric acid, but very slightly so; in muriatic acid its solubility is promoted by the presence of iron in combination.

It is very difficult to produce the sulphuret of zinc artificially, on account of the indifference of the metal to sulphur; yet it is difficult by simple roasting to decompose the blende, which requires nearly a white-heat to cause the evolution of the sulphur as sulphurous acid, leaving the zinc as an oxide. The composition of four varieties is shown in the following analyses:—

		Bagnéres de Suchon.	England.	Przibram.
Sulphur	32·630	33·600	33·000	33·150
Zinc	66·630	63·000	61·500	61·400
Cadmium	..	..	..	1·500
Gangue	..	..	1·500	..
Iron	0·740	3·400	4·000	2·290
	Thomson, 100·000	Berthier, 100·000	Berthier, 100·000	Lowe, 98·340

Proust has given the analysis of a blende containing only 15 per cent. of sulphur. In some, gold is said to be present.

As the ores of zinc are most commonly raised with other ores, the method of mining and of preparing for the smelting-house does not require a separate notice. Calamine is prepared for smelting by calcination in a sort of lime-kiln, or in a furnace resembling an iron cupola furnace, assisted with a moderate blast, as shown in Fig. 161 of a Schaftofen. The ore, mixed with coal or coke, is thrown into the mouth of the furnace A; and as the calcined ore is drawn from the furnace at E, it gradually finds its way down into the hotter parts of the furnace, B and C, until at D it meets with the full force of the blast from the tuyères FF; and the heat produced is sufficient to evolve the whole of the carbonic acid and any sulphur that may have been present. The calcined ore is ground to fine powder before mixing with the quantity of carbonaceous matter necessary for the decomposition of the oxide of zinc contained in it.

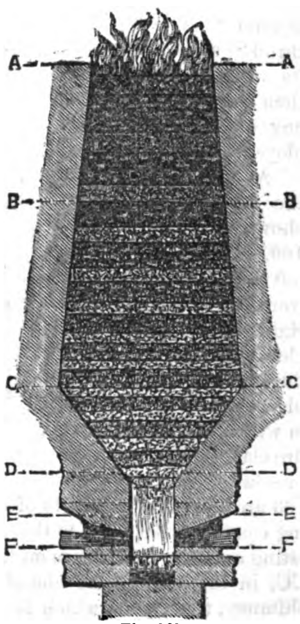


Fig. 161.

The heat is sometimes maintained in the kiln without a blast, by having four fire-places arranged around the throat of the kiln, so that the heat produced may be drawn into it, and regularly distributed throughout.

The siliceous calamine is subjected to the same sort of calcination. The constitution of the calcined products is shown in the following analyses :—

	I.	II.	III.	IV.
Oxide of zinc, free . . .	16·400	27·100	50·000	64·700
Do. combined with silica	56·400	13·160	7·020	..
Silica	21·200	6·480	2·640	..
Oxide of iron	5·800	53·400	32·940	8·300
Oxide of manganese . .	..	..	6·480	..
Carbonic acid and water .	..	..	..	7·200
Oxide of lead and loss . .	..	..	0·920	..
Sand	..	..	..	19·500
	99·800	100·140	100·000	99·700

The three first analyses are by Schmidt, the fourth by Berthier.

By calcination, the ore loses about twenty-five per cent. of its weight. The calcined ore, which contains on an average about forty per cent. of zinc, is ground to a very fine powder, sifted through a fine sieve, mixed with half its weight of coal-dust, and is then ready for charging into any of the furnaces employed.

At Vieille Montagne, the furnace used is as shown in Figs. 162 and 163. In Fig. 162, on the left hand, is shown the front elevation; on the right hand, a sectional elevation. BB are small flues leading from the fire-place A, to the chamber in which the small fire-clay retorts represented in Fig. 163 are set. The products of combustion having conveyed the heat to the retorts, by circulating amongst them, pass on through the flues CC, in the arch of the chamber, to the main chimney, the top of which is supplied with a damper. Four of these furnaces stand together

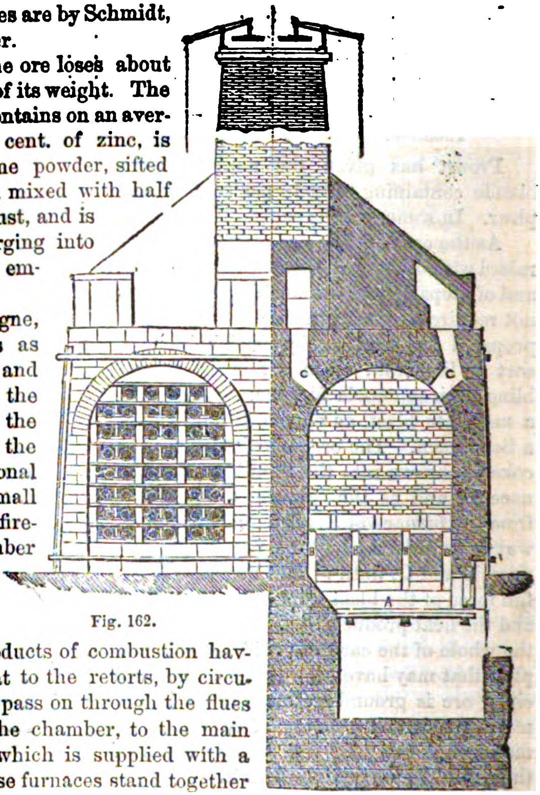


Fig. 162.

for the purposes of economizing room and heat, and of rendering the whole structure stronger. In the arched chamber, which is nine feet high and six feet wide, are placed forty-two cylindrical retorts, each three feet eight inches long, and six inches internal diameter. They are made of a very refractory fire-clay, carefully burnt. Short conical cast-iron pipes are fitted to the mouths of the retorts, projecting through the fire-brick breast-work. On these are adjusted wrought-iron tubes, tapering through a length of two feet to a diameter of an inch at the mouth. The inclined position of the retorts and pipes, and the method of supporting and arranging them in the furnace, are shown on the left hand of Fig. 162, and in the side sectional elevation, Fig. 163. The breast-work is supported with plates of cast-iron, strengthened with wrought-iron braces.

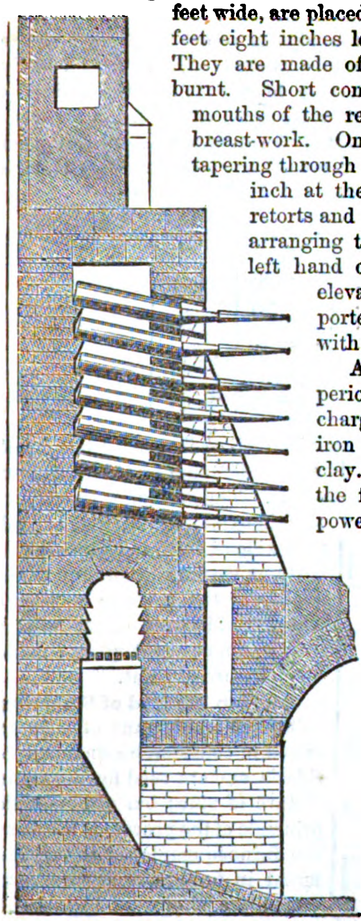


Fig. 163.

A new furnace is slowly heated over a period of four days to a white-heat; small charges of the ore are introduced, and the iron tubes luted into their places with fire-clay. In the course of four or five days the furnace is brought into full working-power. A charge for the set of retorts in one furnace consists of 1100 lbs. of calcined calamine, mixed with 550 lbs. of coal-dust. The retorts are charged with quantities of the mixture placed in a sort of semi-cylindrical scoop, varying according to their position; for in spite of every precaution to heat all the retorts alike, those nearest the fire obtain most heat, and therefore work off quickest. As soon as the retorts are charged, the iron pipes are properly adjusted in their places, and the full force of the fire is put on. Soon carbonic oxide gas is evolved in considerable quantities, which burns with a blue flame at the mouths of the wrought-iron pipes. Gradually the quantity of the gas diminishes, and the flame obtains a greenish-white hue, and white fumes are copiously evolved, when the distillation of the metal commences. The purer metal is deposited in the cast-iron pipe; and the metal alloyed with lead is condensed in the outer wrought-iron tube —proving that, although alone lead is not volatile, yet that when in combination with zinc it is more volatile than zinc itself. When the wrought-

iron pipe appears to be nearly filled up with the condensed products, it is removed, and its contents are shaken or scraped out. The liquid metal lying in the cast-iron pipe is raked out by one workman into the ladle supported by another. The wrought-iron pipe is again luted on, and the same process repeated until the charge is worked off, which is usually done in twelve hours. The charge having been finished, the residuary matters in the retorts are scraped out; they are again charged, and the work conducted as before. The crude metal obtained amounts to about thirty per cent. of the calcined ore employed. The composition of the residuary matters in the retorts is shown in the following analyses by Berthier:—

	Liege.	Iserholne.
Zinc and oxide of zinc	8·60	51·20
Iron and oxide of iron	10·00	2·60
Silicate of zinc	57·50	..
Lead	trace	2·00
Sand and clay	19·00	..
Carbon	4·90	43·40
	100·00	99·20

The fused zinc scraped out of the cast-iron pipes is poured into ingot-moulds containing 75 to 85 lbs. each. The granular zinc is melted in cast-iron pots, skimmed, and cast into ingot-moulds. The residuary skimmings contain oxide of zinc, oxide of lead, protoxide of iron, and sand, in proportions varying according to the quality of the raw ore employed. These residua are either worked over again, or are employed in the manufacture of paint.

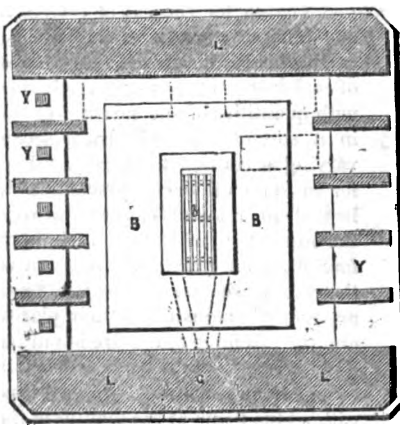


Fig. 164.

Silesian Method of Smelting.—The calamine ores of zinc are raised in considerable quantities in Silesia, and are used for the manufacture of zinc; but although the principle of the process is the same, the furnace employed is very different in form and arrangement, which are shown in Figs. 164 to 168. Fig. 164 is a plan of the furnace at the level of the fire-bars, *b*. The fire-place and bed of the furnace, B B, are built of fire-bricks and tiles. The ash-pit, A, is shown in Figs. 165 and 166. As the same letters are used in each figure, the positions in the plan may be identified with those in the two vertical sections, both through the central line of the furnace, but at right angles to each other. The dotted lines in Fig. 164 show the places of the muffles, F F, of Fig. 165, which places are also shown

at Y Y, in Fig. 166. L L are the sides, braced together with iron-work, and supporting the thrust of the arch, E. The coals, fed through the fire-place, C, on to the fire-bars, *b*, receiving the draught through the ash-pit, A, give off the heat to the interior of the furnace, in which the ten retorts, or muffles, F F, are arranged; the smoke passing off by four holes, K K, in the roof of the furnace. In the plan, Y Y are the holes through which the conducting-pipes, H, have access to the chambers, *i i*, of which there are ten, corresponding to the number of the retorts. The arch, E, is constructed of a mixture of fire-clay and sand, carefully beat down, about nine inches thick, on a mould of wood, or temporary rough masonry, smoothed over with ashes or sand, which is removed after the arch has been allowed sufficient time to harden, so as to stand without support. If properly made and carefully dried, this arch will last two or three years. The muffle, shown in longitudinal and transverse section, FF (Fig. 167), is about forty inches long, twenty inches in height, and two to three inches thick. It is made of a mixture of fire-clay and old broken muffles, ground to coarse powder, moulded, slowly dried, and while the furnace is being heated, which requires eight to ten days, the set of muffles is prepared by baking in a separate furnace, slowly raising them to a strong red heat, and then, while so heated, removing them to their assigned places in the reducing-furnace, where the fire-clay door is fitted, and the condensing-pipes, H H H and C, are adjusted, so as to convey the metal into vessels placed to receive it at *i i*, in the recesses of the arch Y Y. As, until the pipes have attained a considerable temperature, the metal is apt to condense in the pipe, H, and so to choke it,—in the end of the pipe, H, a hole, provided with a clay stopper, is left, through which the metal may be raked out, without disturbing the pipe itself. The pipe H is connected with the receiver I by the adapter G, passing

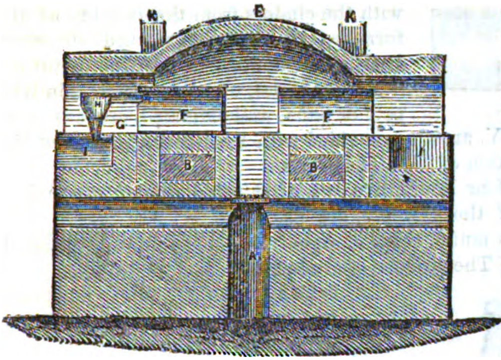


Fig. 165.

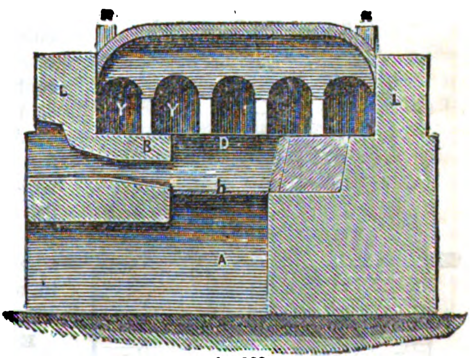


Fig. 166.

through the holes Y. The charge is introduced through a hole in the fire-clay door below that provided for the adjustment of the pipe. The calamine used is calcined in a reverberatory furnace, heated with a separate fire, or in some instances with the heat passing off from the reducing furnaces. The charge of calcined calamine, roughly powdered, is mixed with powdered coke, or with the cinders from the coal-fire of the furnace. A charge is worked off every twenty-four hours. The product obtained is a crude metal, which is remelted in iron pots or pans, well skimmed, and cast into ingots. The chambers, Y, are also provided with iron doors, to protect the pipes from the cooling action of the atmosphere.

Fig. 167.

In the day of twenty-four hours, five cwt. of calcined calamine, equal to seven and a-half cwt. of the raw ore, are passed through the furnace, each muffle being charged and drawn once in that time. The produce of crude zinc is 2·4 cwt., which by refining is converted into 2·05 of commercially pure zinc, and ·35 cwt. of skimmings, which contain ·2 of metallic zinc; thus the product of pure zinc from raw ore by this process amounts to only 27·4 per cent., whilst it contains as much as 45 per cent. on the average.

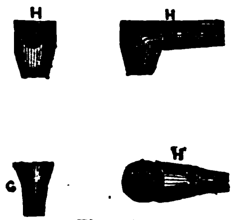


Fig. 168.

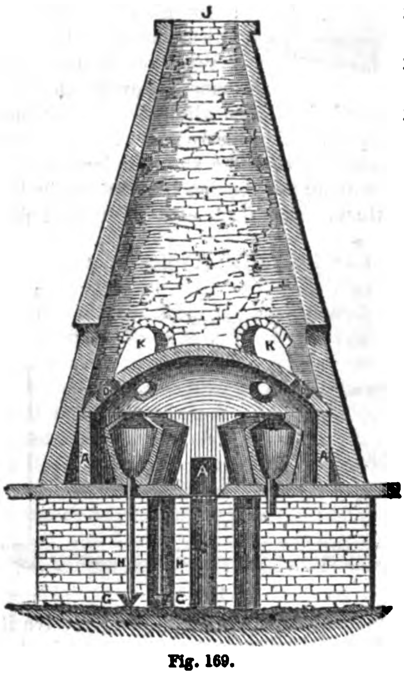


Fig. 169.

A modification of the Silesian furnace is sometimes employed, in which as many as twenty-four muffles are set, and the heated gases and smoke are carried off through adjacent reverberatory furnaces, in which the roasting of the raw ore is carried on.

English Method of Smelting.—There are but few zinc-smelting works in Great Britain; many of those that were in operation have been abandoned, on account of the cheap rate, consistent with superior quality, at which the metal was supplied from the continent, principally by the Vieille Montagne Company. This arose chiefly from the superior quality of the ores obtained by them, and, in conse-

quence of their great abundance, their less cost. Within the last year or two, zinc smelting has been reviving in this country, and an increased demand has arisen for the blende ores, which are more abundant here than the calamines. During the year 1855, the total quantity of calamine reported to have been raised, or rather sold, was 182 tons, the produce of the Alston Moor Mines; but of black-jack or blende, from various mines, 9620 tons. Although these quantities are not to be considered as all the ores raised in the different mines, yet they will show the comparative quantities of the ores obtainable.

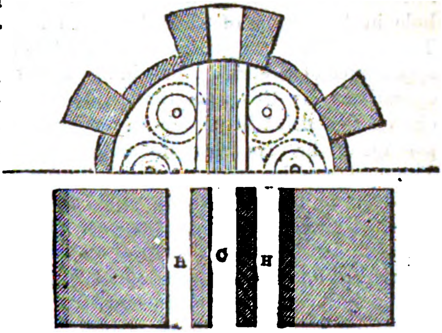


Fig. 170.

The black-jack or blende, and so also the calamines, are roasted in reverberatory furnaces resembling those employed for the calcination of tin or of copper ores; but the black-jack requires a longer time and a greater heat than those ores do. The reduction furnace, for the treatment of the calcined ores, is shown in Figs. 169, 170, and 171.

Through a solid mass of masonry, H H, are three passages, shown in both the plan and elevation. These are intersected by another, at right angles, through the middle. The middle passage of the three, C, is the ash-pit of the fire-place, A. The others are required for the descending-pipes from the large pots, or crucibles, arranged on the hearth above, on each side of the fire-place, within a circular fire-brick wall, A A, suitably braced, and supporting a dome or arch, of the same material, through which, over each pot, are holes, OO. Through these the pots are charged, and the smoke from the fire passes into the main chimney, G, which is like a glass-house chimney. In the large chimney are doorways, K K, opposite each of the arches in the circular wall of the furnace A, through which the pots are passed into their places on the hearth. The inner arches are built up with fire-brick after the pots are put into their places; but the outer doorways are of course left open, for free access to the furnace for charging, &c.

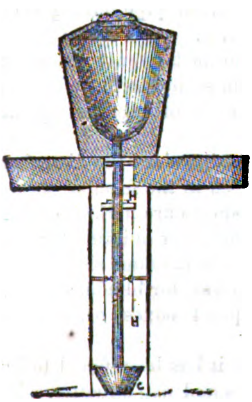


Fig. 171.

The construction of the pot is shown in Fig. 171; the pot is so placed on the hearth, that the hole in its bottom shall correspond with the iron condenser-pipe, which passes through the hearth to the passage below. A luting of fire-clay is interposed between the pot and the condenser-pipe,

which is also connected with a larger cylindrical pipe of wrought-iron, sufficiently long to convey the condensed products of distillation into the vessel G. The pots are made of a mixture of fire-clay and coarsely powdered broken pots; they are carefully baked in an adjoining furnace, whence, when they are required to supply the places of broken pots, they are conveyed red-hot into the furnace by a large pair of tongs on wheels. If well made, a pot will last about four months. The charge of calcined ore and coal, mixed, is introduced through the holes in the crown of the arch into the crucible, the hole in the bottom of which has been loosely stopped with a wooden plug. The cover of the crucible is left off for two hours, after charging, or until the appearance of a bluish flame indicates the commencement of the reducing operation. By this time the wooden plug will have been converted into charcoal; and it will have been rendered sufficiently porous to allow of the passage of the vapours of the metallic zinc on their way into the condenser. The workman has only to maintain the fire, and occasionally to clear a passage in the condensing-pipe, should the metal have accumulated sufficiently to endanger its stoppage. This clearance is effected by passing a red-hot bent iron rod through the accumulated metal. Five charges of ore are worked off in a fortnight, eight to ten tons of calcined ore having been used, with a consumption of twenty-five to thirty tons of coal, the production of metal amounting to about thirty-five per cent. The crude metal obtained in drops and powder, with a little oxide of zinc, in the dishes placed on the lower hearth, are purified in the same manner as the products of the Silesian process. Before a new charge is put into the pot, the residuary matters are raked out through the bottom, the sheet-iron pipe having been temporarily removed, and the charcoal plug withdrawn.

Many patents have been taken out during the last twenty years for improvements in zinc smelting; but not one of them seems to have been of sufficient practical importance to have been the means of superseding the old processes.

The consumption of zinc has been rapidly increasing since the discovery of the means of laminating it with facility. It is used in the form of sheets for covering ships' bottoms instead of copper: the sheets are nailed on with zinc nails. The sheets are also used plain or corrugated for building houses, boats, ships; for constructing roofs; for making baths, rain-gauge shutes, and spouts; perforated in a great variety of ornamental forms for blinds, screens, light fences, sieves; also for water-tanks, water-proof boxes, ornamental vases, &c.

As zinc becomes very fluid at a low temperature, it has been found to be exceedingly well adapted for making casts of statues and of statuettes, as it takes a sharp impression, from the filling up of every outline, therefore leaving but little labour for the chaser. In France, the production of statuettes in zinc has become an important business; and beautiful works of art of fair execution are now becoming attainable, through this branch of industry, by individuals whose disposition to cultivate a taste for the Fine Arts has hitherto been curtailed by the limited means at their disposal. The

use of the metal in the preparation of various alloys, has already been noticed. It has also been employed, like tin, for the coating of iron, producing what is known as galvanized iron. Utensils and portions of machinery, both of wrought and of cast iron, are galvanized, by first pickling them with dilute sulphuric acid, then dipping them into a solution of chloride of zinc, drying them, and finally placing them in a bath of zinc, melted, covered with fused chloride of zinc. By leaving them until of the same temperature as the bath of metal was before the article was immersed, it becomes perfectly coated with zinc, which remains adhering to the iron with a perfectly smooth surface. The article should be subsequently well washed in water and a solution of soda, otherwise a great tendency to oxidation will be produced by adhering traces of the chloride of zinc.

The chloride of zinc in concentrated solution is largely employed as a disinfectant; it is known as *Sir William Burnett's disinfectant liquor.* The sulphate will serve very nearly, if not quite as well, for the same purpose; as indeed will many other metallic and earthy salts.

The oxide of zinc is much used as a white paint. Ground with oil, it does not cover so well as the white-lead paint; but it is free from the objection to the use of white-lead, as it is not liable to tarnish or blacken when exposed to the action of sulphuretted hydrogen.

The use of white-lead paint is injurious to the health of the painter, and of persons exposed to the smell of freshly-painted rooms, where it has been used; but zinc oxide is also free from this objection.

CHAPTER XXX.

ANTIMONY, BISMUTH, AND LEAD, THEIR ALLOYS AND SYNONYMES.

Synonymes: Antimony (Regulus of Antimony); Antimoine, *Fr.*; Spiessglanz, Spiessglas, Spiessglanzkonig, *Ger.*; Antimon, Antimonium; Stibium, Sb.—This metal was not known until the fifteenth century; it was first described by Basil Valentine. Some of its compounds were known to the ancients: it is spoken of by Pliny as Stibium. The black sulphuret was used by the Egyptian and Roman ladies as a cosmetic for marking the eyes and eyebrows. It is said that Basil Valentine, a monk of Erfurth, while engaged in his alchemical labours, threw some of the preparations of antimony where pigs had access to the mixture with their food; and having observed that after becoming sick they rapidly fattened, he thought that his friends might profit by the same treatment—and so he fed them in like manner with the swine; but, to his disappointment, found that what was good for the pigs was bad for the monks, for they died: and so the metal obtained the name of antimoine, anti-monk, antimony.

From the earliest times the sulphuret of antimony was known as *alcofal*—an Arabic term for an impalpable powder, the condition in which it was used as a cosmetic. Hence the terms of the alchemists, *aloophal* and *alcosol*, and the *alquifour* of the potters, applied to the fine powder of the sulphur of lead. *Alcohol*, now of very different application, was derived from the same source.

Antimony, in many respects, resembles arsenic in its properties; but its oxides, unlike those of arsenic, are insoluble in water. It is of a grayish-white colour, highly crystalline, and brilliant in its fracture; not very hard, but brittle, and easily reduced to powder. It has a peculiar taste and odour. Its tenacity is very feeble; it melts at a red heat. Out of contact with air, it volatilizes very slowly at a white heat, more rapidly in the open air. Covered with a flux in the strongest white heat, it loses only one one-thousandth of its weight; but it may be distilled at the same temperature in a current of hydrogen gas. Its specific gravity is 6·715. In dry air it continues unchanged, but in a moist atmosphere it becomes coated with a thin covering of oxide. It does not decompose water, either at ordinary temperatures, or at that of boiling water; but at a red heat it does so rapidly, sometimes with explosion. At a red heat, exposed to the air, it burns with a white flame, producing a crystalline oxide. Nitric acid acts energetically on it, converting it into antimonious acid, which is insoluble in water. Dilute sulphuric acid has no action on it. By boiling in concentrated sulphuric acid, a sulphate of the protoxide is produced, with evolution of sulphurous acid. It is not soluble in hydrochloric acid, nor is it so even in hot acid, if pure; but if associated with iron it is very slightly soluble. It dissolves very readily in nitro-muriatic acid, and sulphurous acid has a slight action on it

The nitrate, chlorate, and sulphate of the alkalies, at a red heat, oxidize it very readily. It is insoluble in organic acids. In the form of powder, dropped into chlorine, it takes fire, producing protochloride and perchloride of antimony. An alloy of antimony and zinc, by digestion in dilute sulphuric acid, evolves hydrogen gas, holding antimony in solution, the product being hydrogen and antimoniuretted hydrogen.

Native metallic antimony is very rare; but it is found at Dauphiné in France, Andreasberg in the Hartz, Sweden, Meissen, and Connecticut, U. S. It is sometimes alloyed with arsenic, but is most commonly mineralized with sulphur, more rarely oxidized, as an antimoniate of lime, or in combination with other metallic sulphides, such as jamesonite, bournonite, feather ore, antimonial copper glance, fahlerz, gray copper, ruby silver, polybasite, &c.; but the only ore used as a source of this metal is the sulphuret of antimony, obtained principally from Borneo and the East Indies; it occurs also in Cornwall, in several mines in Devonshire, Scotland, and the same localities in which the metal is found. It is known also as gray antimony, stibine, and prismatoidal antimony glance. It is a bluish-gray mineral; fibrous, radiated and granular structure; metallic lustre, occurring in masses with quartz, sulphate of barytes, carbonate of iron, and carbonate of lime. It not unfrequently contains traces of gold, and sometimes of silver; it is brittle, and easily reduced to a black powder. It is fusible at a very low temperature; its composition is—

Sulphur . . .	26
Antimony . .	74
	100

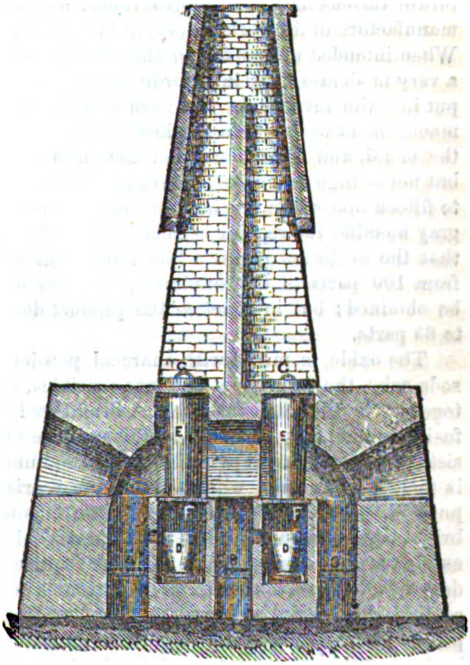


Fig. 172.

From its easy fusibility, instead of being dressed with water, as is usual with other metals, it is melted out from its gangue by fire. The furnace shown in Fig. 172 is one of the best employed for this purpose. Between the three fire-places A B C, are two chambers F, covered with cast-iron plates, having holes corresponding to the centres of the two fire-clay cylinders E, which are fitted on them within the arch,

through which the fires play around them, the smoke passing off by flues at the back into the chimney above the platform. The cylinders have holes in the bottom at the sides, corresponding with the openings into the arch: these holes are closed with fire-clay stoppers, luted with fire-clay. Within the chambers F, on low carriages, are placed the crucibles D D, as receivers of the fused ore which flows down from the cylinder above. The furnace having been heated to a bright redness, the charge, of four hundredweights of crude sulphuret in small lumps, is put into the cylinder E, and the cover C is put on; the ore soon fuses and flows down into the crucible below, leaving the stony gangue in the cylinder, which is recharged every three hours. The residuary matters are drawn out through the holes in the side of the cylinder. About 90 lbs. of the pure sulphuret are obtained per hour. A small reverberatory furnace, like a tin reducing furnace, carefully managed by the workman, will produce equally good results at less cost of fuel and of plant. Much of the refined sulphuret thus obtained is used as it is, for the manufacture of various medicinal preparations; and it is extensively employed in the manufacture of fireworks, especially for the production of white signal lights. When intended to be used for the smelting of the metal, it is first roasted at a very moderate heat in an ordinary calcining reverberatory furnace. It is put into the furnace in the form of a coarse powder. It requires careful management to maintain the heat sufficiently high to cause the oxidation of the metal, and the evolution of the sulphur to go on without interruption, but not so high as to cause the fusion of the sulphuret. At the end of twelve to fifteen hours, the calcination will be complete, the charge having lost its gray metallic lustre, and become of a cindry-gray colour, at the same time that the evolution of the white fumes will have ceased. By this process, from 100 parts of the sulphuret, 86 parts of oxide of antimony ought to be obtained; but in practice the product does not amount to more than 60 to 65 parts.

The oxide is mixed with charcoal powder, moistened with a solution of soda-ash; the mixture is put into crucibles, a number of which are placed together in the same furnace. A bright red heat is maintained until the fusion is complete. The product is a crude metal and a scoria, which consists of the sulphurets of antimony and sodium in combination. The former is melted over again with some of the scoria, by which it is still further purified. The crude metal cast into ingots, when broken, presents a bright crystalline appearance; but the crystals are small, and not as bright as they are required to be, to meet the requirements of ordinary commercial demands. By remelting in large quantities, skimming carefully, and slowly cooling, the desired appearance may be obtained. The scoria, ground to powder, is known as *crocus* or *kermes*. Antimony is also obtained indirectly in some of the processes for refining lead.

Metallic antimony is but little used alone; it is principally employed for the production of alloys, in which it serves the purpose of hardening. Its action on gold is very remarkable. One part of antimony, with one thousand parts of gold, is sufficient to destroy the working properties of it. From this

peculiar action, the ancients gave it the name of *regulus*, or *little king*. The alloy of antimony and iron, in the proportions of 3 iron and 7 antimony, is white, very hard, and brittle, slightly magnetic, and fusible. The principal alloy in use is that of antimony and lead, in the proportions of 4 lead and 1 antimony for type metal, 6 lead and 1 antimony for stereotype metal. Britannia metal consists of 100 tin, 8 antimony, 2 bismuth, 2 copper. Pewter is sometimes made of 12 tin and 1 antimony.

The oxide of antimony, or antimony glass, is used in the manufacture of enamels, and of coloured pastes for imitation gems.

Bismuth.—This is a rare metal, but its distinguished qualities are that it is very fusible, and causes other metals to become so. It melts when pure, at 480°; it may be distilled in a close vessel, and then crystalizes in lamina, It is very brittle, like antimony, and of a brilliant lustre; its colour is white, tending to flesh-colour. Its specific gravity is 9·83, which may be increased to 9·88 by hammering. It expands in the act of cooling, which renders it peculiarly suitable for castings.

There are many minerals which contain bismuth, but they do not often occur in such quantities as to make the extraction of the metal profitable. The metal is not very valuable, and notwithstanding its scarcity, it is sold at a low price. It occurs native, and is then easily obtained. Native bismuth is found in Amèrica, where it is associated with wolfram, galena, blende, and quartz; both in Monroe county and South Carolina; and, of course, in many other parts of the world. Sulphuret of bismuth occurs at Haddam, Connecticut. The carbon is found in the gold district of Chesterfield, and South Carolina; and the sulphuret, and lead, and copper, at Lubec lead mines, in Maine. Telluric bismuth exists in the gold regions of Virginia, and North Carolina. All the metal in market is obtained almost exclusively from cobalt-speiss, at the smalt works of Germany. The residuum, from which also nickel is extracted, contains on the average, seven per cent. of bismuth.

The compounds of bismuth are distinguished by fusibility, at a lower degree of heat than most metals. Eight parts of bismuth, 5 lead, and 3 tin, melts at 202°. Two bismuth, 1 lead, and 1 tin, melts at a little lower heat. The addition of mercury increases the fusibility of these alloys. One bismuth, 2 tin, and 1 lead, is soft solder for pewter. Clichés and stereotype metal may be composed of 3 lead, 2 tin, and 5 bismuth; this alloy melts at 199°; 45·5 bismuth, 28·5 lead, 17 tin, and 9 mercury, is an alloy for plugging teeth; it fuses at 149°. An amalgam of 20 bismuth, and 80 mercury, is used for silvering the interior of glass globes. Like antimony, bismuth readily forms an alloy with the alkaline metals. Its affinity for arsenic is very weak, like that of phosphorus; both of these substances may be evaporated from the hot metal almost entirely. All its compounds with precious metals are very brittle. Bismuth has been proposed instead of lead for refining silver; but the experiments performed with it were not satisfactory. A compound of tin and bismuth is stronger, harder, and more sonorous than pure tin; and

for these reasons it is added to pewter. An alloy of equal parts of lead and bismuth is heavier than the mean density of the two metals, it being 10·709.

Bismuth is scarcely ever used alone; it is chiefly employed for imparting fusibility to alloys. Besides the above-mentioned applications, it is used in the alloys of which safety-plates and plugs in steam-boilers are made. Its oxides are used as cosmetics; also as paints and printing colours.

The operation of smelting bismuth is extremely simple; the metal having but a weak affinity for other substances, is obtained by simply heating its ore, in a liquation furnace in a cast-iron retort, set at an angle, at the highest part of which the crude ore is charged; at the lowest angle is placed a cast-iron bowl, into which the metal flows. About half a hundredweight of broken ore is charged in each retort, of which there are usually four in a furnace side by side. This quantity nearly half fills a retort, so that the upper part of it is empty. The lower end is closed with a clay plate, or slab, provided with an aperture for the discharge of the melted metal. The pipes, when properly ignited, soon cause the metal to flow into the dish, which contains some charcoal-dust. By applying a brisk fire, and stirring the ore, all the metal contained in it is obtained within half an hour, the residuum is scraped out of the retort into a trough with water, and the pipes filled afresh. About a ton of ore is smelted in a day of eight hours. The metal is remelted, cast into iron moulds in the form of ingots, and is now ready for the market.

The metal thus obtained is not pure; but it may be purified by remelting in a flat earthen, or rather a bone ash-dish, at a low heat, removing the dross as it appears on the surface of the metal. It is advisable to melt the metal thus obtained in a purer form, in a black-lead pot, and then cast it into the mould for ingots. Bismuth cannot be freed from silver by these means, in consequence of which the article of commerce always contains some of that metal.

Lead.—This is a metal generally known. When pure, it is blue-white, of high lustre, and extremely soft. It is almost inelastic, and may be bent, when in sheets, like leather. This softness admits of its being used, like graphite pencils, for writing on paper. Its specific gravity is 11·44; or, when pure, only 11·35. Lead admits of being rolled into thin sheets, and is easily drawn into pipes; it has little adhesive strength. It melts or crystallizes at 600°; some assert that it does not melt at that degree of heat, but at 20° higher. A variation in the melting heat may be observed with most other metals: impure being always more fusible than pure metal. When common lead is exposed to a melting heat, its point of fusion rises with the time it is exposed to that heat. At a white heat lead evaporates, and it may be obtained crystallized when the heat is gradually diminished; sudden cooling prevents the formation of large crystals. All the lead of commerce contains iron, copper, and until Mr. Patinson's discovery, more or less silver.

A large number of minerals contain lead; but the chief source of this metal is galena, from which ore lead is chiefly obtained. Lead occurs

native, but it is of little practical use. It occurs in combination with sulphur, selenium, tellurium, antimony, oxygen, and other substances. Most of the varieties of lead ore enumerated in mineralogical works, occur in combination with the above; few of them, however, are used for the manufacture of the metal; these ores form mere cabinet specimens.

The principal lead mines in Great Britain, are in Cornwall, Devonshire, Somerset, Derbyshire, Cumberland, Westmorland, Denbighshire, Monmouthshire; in Scotland, on the borders of Dumfriesshire, and Lanarkshire; in Ireland, Wicklow, Wexford, Clare, and county Down. Phosphate of lead occurs at almost every lead mine, as a faint green or gray substance, either crystallized or without definite form; chlorides, sulphates, and other salts of lead are also found; but they are of little interest to the metallurgist.

Sulphuret of lead may be considered the matrix of all other lead ores; where they exist, we are sure to find galena. It is always crystallized, however minute the crystals may be. The form of the crystal is a cube, composed of rectangular plates. The colour of the ore is gray, similar to that of the polished metal, which it also resembles in lustre. It forms a gray metallic powder, when rubbed. Its specific gravity is 7·3 to 7·7. Galena consists of 86·66 lead, and 13·34 sulphur. The ore contains also, at times, selenium, zinc, silver, copper, antimony, and other metals. Silver is the most valuable of these admixtures, and is now extracted from the metal by a process first invented and patented by Mr. Pattinson, Newcastle-on-Tyne. This operation is as follows:—a series of hemispherical iron plates are ranged side by side, each having a separate fire-place. One of the pots is charged with about five tons of lead; when melted, the surface is skimmed in order to remove the impurities thrown up. The fire is then withdrawn, and the lead gradually cooled. When the process of crystallization begins, the crystals are withdrawn by means of ladles, perforated so as to allow the uncrystallized portion to run through; the crystals retained in the ladle are transferred to the second pot, where they are again melted, and again crystallization takes place. This process is continued until the remaining portion of the lead is so rich in silver as to contain from two to three hundred ounces per ton, which is extracted by the process of cupellation.

German galena contains from ·03 to ·05 per cent. of silver; the English, ·02 to ·03; the ore at Monroe county, 3 per cent.; Eaton, North Havanna, ·1 per cent.; and that from the State of Arkansas may contain from ·003 to ·05 per cent. Galena occurs in beds and veins, both in crystalline and stratified rock. It is often associated with blende, iron ore, copper pyrites, and a variety of other lead ores. It occurs in gangue of heavy spar, calc spar, quartz, and other substances. The most extensive deposits of it in the United States, are in Missouri, Illinios, Iowa, Wisconsin, Arkansas, Virginia, North Carolina, and California. The lead ores of Missouri extend over 3,000 square miles. From the Mississippi river, about sixty miles above St. Louis, they extend seventy miles in length, and forty-five miles in width, over a sterile rolling country, a highland prairie. The soil is reddish, coloured by iron, with clay, full of flint and quartz pebbles, to the depth of

ten or twenty feet. The lead region of Wisconsin is equally extensive as that of Missouri, if not more so; it comprises about 5,000 square miles, extending into Iowa and Illinois. The diggings, or mines, in these regions, do not often exceed a depth of twenty-five or thirty feet. Immense masses of ore have been extracted from these ditches. Galena is not free from foreign metals, of which silver is always present. This ore is, therefore, not only an accidental silver ore; but it may be considered argentiferous in all its varieties. The amount of silver in lead ore, is easily ascertained by an assay, and ought to be thus determined when it is doubtful. As a general rule, we may state, that the purest kinds of galena contain the least silver. The ores of the secondary and younger formation, particularly the ore of the limestone of that period, is always poor in silver. All deposits of galena which occur in heavy masses, are also poor in silver. Galena which in small veins ramifies a stratified rock, is generally rich in silver, and the smallest branches and forks are richest. The heaviest deposits of galena occur in limestone rock. The dimensions of a vein diminish as it penetrates sandstone strata, and grow still smaller in traversing shale or slate. In these rocks the metal is frequently replaced by clay or fragments of rock, and the vein does not show any ore.

A very extensive use of the alloys of lead is made in type metal. Nine lead, and 1 antimony forms common type metal; 7 lead, and 1 antimony is used for large and soft type; 6 lead, and 1 antimony for large type; 5 lead, and 1 antimony for middle type; 4 lead, and 1 antimony for small type; and 3 lead, and 1 antimony for the smallest kinds of type. Type metal frequently contains tin, copper, bismuth, and other metals. Stereotype metal is generally lead alloyed with antimony, in the rates of four to eight of the former, to one of the latter; to this is always added some bismuth, tin, and frequently a little copper. Soft solder varies from 66 lead, to 33 lead in 100 parts, the rest is tin. A small amount of bismuth renders lead tougher; equal parts of each and bismuth, form a brittle alloy. Lead and tin melt together in all proportions, forming a harder and tougher metal than either alone. A small addition of lead to brass causes the latter to be tougher and more suitable for use in the machine shop. Lead has a strong affinity for carbon; oxide of lead mixed with fine carbon, and heated in a covered crucible, forms a black carburet of lead. Lead unites with potassium or sodium like antimony, but does not absorb so large quantities of the alkaline metals as the latter. Arsenic has a strong affinity for lead, and combines with it on covering melted lead with arsenious acid; arsenic-lead and oxide of lead is thus formed. This alloy, 98 lead, and 2 arsenic, is used for making shot, by dropping the fused metal from a high elevation in a shot-tower, into a basin of water; or throwing the fluid metal down a stack of limited height, in which a strong draught of air is produced by a blast-machine. Mercury amalgamates very readily with lead. A rod of lead, bent in the form of a syphon, will transfer mercury from one vessel to another in the same manner as lamp-wick conducts oil. An amalgam of lead crystallizes similar to that of gold, from which the superfluous mercury may be separated, by pressing

it through buckskin. Copper and lead do not combine very readily, they require a white heat for union. The alloy thus formed under the influence of a high heat, must be suddenly cooled, or both metals will separate in cooling. Lead may be separated from copper by liquation, as practised in refining tin; but all the lead cannot be removed by these means; a small quantity always adheres tenaciously to copper. This alloy is brittle; a little lead is injurious to copper. Organ pipes consist of lead alloyed with tin, about half and half. This alloy is cast, instead of rolled, in the desired form of sheets, in order to obtain a crystallized metal, which produces a finer tone. The sheets are formed in casting the metal on a horizontal table, the thickness is regulated by the height of a rib, or bridge, at one end, over which the superfluous metal flows off. The rough sheets thus obtained are planed by means of a carpenter's plane, bent up, and soldered. An alloy of 19 lead, and 29 tin, forms a metal of high lustre, which, when cast over a polished glass or metal plate, shows a most brilliant polish. When ends of glass rods, previously ground to the forms of cut precious stones, are dipped into this melted alloy, convex metal cups are formed, which resemble the sparkling of diamonds. This alloy is soft and cannot bear wiping with a cloth.

The application of lead for pipes, cisterns, and domestic utensils is generally known. It is extensively used in manufacturing white paint, whitelead, and carbonate of lead, The rich colours of chronium are chiefly lead and that metal. The salts of lead are poisonous; and those who make use of this metal for conducting water, or forming cooking utensils, ought to reflect before adopting it, inasmuch as the softer and purer the water, the greater danger is to be apprehended from this pernicious deposit. Lead in sheets is sometimes inserted in foundation walls, for preventing dampness in dwellings. It is worthy of attention, that iron bars, fastened by means of lead into stones, have been protected against corrosion by this metal; we find iron rods in old buildings, which have been preserved for centuries in this manner.

The total annual production of lead may be estimated at about 120,000 tons; of which the United States furnish about 20,000 tons; Spain 30,000 tons; and England 40,000; the remainder is manufactured in other parts of the world.

Although lead may readily be revived from its ores, by applying a moderate heat and by simple means, yet to obtain as much metal as possible at the least cost, has given rise to a variety of forms in furnaces, and methods in the treatment of ores. Galena is reduced simply by melting it in a black pot. If a western backwoodsman wants shot or bullets, he will kindle a fire in a hollow tree or an old stump of a tree, place some galena on the charred wood and melt it down. After cooling, he finds the metal at the bottom of the hollow. Formerly lead was smelted in log-furnaces, in Missouri—a rude kind of square furnace, constructed of logs or stones. The front wall of such a furnace is about eight feet wide, and seven feet high. The hearth in the bottom of the interior is about two feet wide, eight feet long, and ten or

twelve inches high, forming ledges or boshes with the side-walls one foot in width. The arch in front, which admits air into the furnace, is about two feet high and wide, and is temporarily shut by stones, clay, or brick. A basin in front of the furnace receives the fused metal, from which it is ladled into the pig-moulds. The operation in this furnace was simple; a layer of heavy logs was placed horizontally in the bottom: then billets of split wood were set upright, and these covered with galena; the top of the ore was covered by small wood. A fire kindled in the front arch will char the lower parts of the wood first; and by the time the heat is conveyed to the ore sufficient for melting, the hot charcoal below will expel sulphur and precipitate the metal, which flows out as it is formed. One heat requires twenty-four hours, after which the furnace is cooled and the ashes removed; then it is charged anew. About 50 per cent. of metal is thus obtained from the ore. The ashes which remain contain much metal, and are subjected to a second smelting in the ash-furnace. Both these kinds of furnaces are now obsolete; they are replaced by more perfect ones.

In the system of smelting lead ores there is more variety than in any other class of smelting operations. We shall describe these methods, and allude to such apparatus and operations only, as are approved of at the present time.

The method of smelting lead at the north-western mines in Wisconsin, Missouri, and the adjoining States, is to pick the ore well by hand, and remove gangue, which consists chiefly of heavy spar and quartz, and then smelt it in reverberatory or blast-furnaces. The rich slags obtained by these processes are once more subjected to smelting in a slag-furnace. There is not much difference in the form of the reverberatory-furnaces for smelting lead or other metals. The furnace-hearth for smelting lead is about eight feet long, and six feet wide; the arch is twenty-four or twenty-six inches above the bottom. There are two or three small work-doors on each side of the furnace, besides the tap-hole for the metal, and one for the scoria. The hearth is formed of poor refractory slags, firmly rammed down to form a basin towards the tap-side. From this side the metal is run into an iron kettle, from which it is ladled into moulds. In the middle of the roof there is an aperture for charging the ore into the furnace.

When the furnace is heated and charged with about a ton of ore, a gentle heat is applied for the first two hours. All the doors are closed during this interval, and the register at the chimney is lowered. During this process of sweating, some metal is separated, and gathers in the basin of the furnace. When the ore is thus uniformly heated, some fine charcoal is thrown into the furnace and mixed with the slag. The metal thus formed is tapped off, the heat raised, and then the slag is diligently stirred. When the charcoal mixed with the ore is nearly consumed, more is thrown in, and the slag and coal are turned over together by means of paddles, or iron bars flattened at one end. This operation of alternately throwing in fine coal, mixing it with the ore and tapping metal, is continued until nearly all of it is exhausted from the ore. The heat in the furnace is a dull red heat, kept

up rather by means of the burning sulphur than the combustion of any fuel in the grate. When the metal is nearly extracted from the ore, the heat is gradually raised on it. At last some few shovels-full of quicklime, with some charcoal, are thrown in, and this mixed with the ore, and to it a strong heat is imparted. This generally brings out all the metal which can be obtained, and which amounts to about seventy-two per cent. of the ore at the western furnaces. The slag which is removed after the charge is exhausted, is subjected to re-smelting in the slag-furnace. About four hours are required for one heat at a furnace; smelting about four tons of metal in twenty-four hours.

The blast-furnaces in use for the reduction of galena, are about six or seven feet high, and twelve inches wide. They are worked by a tuyere in the back of the furnace. The interior does not materially differ in form from a common cupel oven, with the exception of being square, and having an open tymp; it requires no particular description. The operation of smelting, which we shall describe hearafter, is very simple. In the western states the furnace is fed with charcoal, of which ten bushels are consumed for smelting one ton of lead; besides 1-10th of a cord of wood. Three thousand pounds of ore furnish about a ton or 2,100 pounds of metal, which makes the yield seventy per cent. Three hands are required to attend a furnace.

The slags obtained from the reverberatory and the blast-furnace, and those from all ash-furnaces of the lead region, are re-smelted in the slag-furnace. This is a low furnace about two and a half or three feet high, and about twenty-four inches square, or the horizontal section forms an oblong of twenty-two by twenty-six inches. The hearth in which the reduction is performed, is constructed of cast-iron plates, so that no lead may be lost in dissolving the hearth-stones. The front-plate is exposed to the fire, the others are covered by heavy charcoal dust; the bottom slopes very much. Some of these furnaces are not provided with iron plates; they are consequently much exposed to injury by the fused slag, and cause in consequence, loss of metal. In front are two iron basins, one receives the melted lead and scoria as they issue from the furnace; the lead remains in the first, and the scoria runs over the top of it into the second basin, and as this is filled with cold water, it is cooled, flies into small pieces, and is thus shovelled out and thrown aside. The slags before they are subjected to reduction in these furnaces, are either pounded in a stamping mill, in order to recover grains of metal which may happen to be inclosed in them, or are simply broken into pieces of the size of a hen's egg, by means of a hammer or pounder. The yield of a reverberatory-furnace is equal to, and sometimes by smelting rich slags, superior to that of the blast-furnace; 2,500 pounds, and frequently more, lead is smelted in twelve hours. The slags obtained are by no means free from oxide of lead; it contains as much as twenty per cent. of metal. Charcoal is in general use as fuel in these furnaces.

At the English mines the ores are subjected to a mechanical purification before sending them to the smelt-works. The crude ore is assorted by hand, after which it is subjected to grinding between fluted rollers. When the

ore, or a part of it, is so hard as to injure the cast-iron rollers, it is sent to the stamping mill. Ores which are required to be very fine are also stamped, after having been crushed between the rollers. Thus converted into sand, it is washed in order to remove gangue and adhering impurities. The crude pieces are, in some instances, sifted and washed before they are crushed. After the ore has been so far diminished in size as to be suitable for effectual washing, it is sifted into the tossing-tub, or into the jigging apparatus. This is a tub with water, in which a round common sieve is moved by hand, and in directing that motion skilfully up and down, the impurities are brought on the top of the ore. The separation of impurities is essentially effected by hand, the use of sieves and water merely assists this operation. The leading object in this case is to force water through the meshes of a sieve, in which a couple of inches of ore sand is contained; the water in passing through the stratum of ore will raise the light particles above the heavy ones, which finally form the lower stratum in the sieve. It is immaterial to the success of the operation if the water is moved, or the sieve with the ore is moved; the first plan has been successfully resorted to, and a pump made to drive water through stationary sieves. The impure residuum thus obtained, is subjected to washing in a cistern, simply by agitation with a shovel; or, the ore is washed in a short labyrinth.

When the hearth is formed by refuse, or slags of previous smeltings, and settled by heat, the ore is charged through the aperture in the top, to the amount of twenty hundredweights at once. It is subjected for two hours to a gentle heat, so as to expel most of the sulphur; in the meantime all apertures in the furnace are closed. At the expiration of that time, the furnace is opened, and the reduction of the ore gradually accomplished by throwing in small charcoal, stirring the mass, and tapping the metal into the basin. The slag which passes out with the metal is returned to the furnace, and worked with the other slags. When the ore is almost exhausted of its lead, some quicklime is thrown in, a strong heat is finally given; and when all the lead which may be obtained is removed, the slags are drawn out, and a fresh charge of ore is introduced. From four and a half to five hours are required for the extraction of the metal, after which the slags still contain from twenty to twenty-five per cent. of metal. From one-half to three-fourths of a ton of inferior mineral coal is consumed in smelting a ton of lead.

The rich slags produced either in the reverberatory, or in the blast-furnace, are re-smelted in the slag-furnace.

In France the smelting of lead ores is in some places performed in reverberatory-furnaces, with the assistance of iron ore. When the crude ore and slags in the furnace are so far exhausted of their metal, as to yield no more lead by the addition of small charcoal and increased heat, the smelter throws into the furnace some stamped and washed sparry iron ore, instead of lime; this amounts to about ten per cent. of the lead ore primarily charged. This addition stiffens the slag: which is now withdrawn from the furnace, and subjected to re-smelting in the slag-hearth. Nearly all the lead is obtained from the slags in this last operation.

In Germany, generally, the ores are purified by hand; washed, stamped, and washed again, and roasted with salt, or iron, or iron ore.

The roasted ore is smelted in blast-furnaces, which are from twelve to fourteen feet high. The front or tpmp of the furnace is walled up with bricks, which are temporarily put in with clay mortar. The width of the furnace is from twelve to fourteen inches square or oblong. The hearth or bottom of the furnace, is formed of a mixture of loam and charcoal dust firmly rammed in. The basin outside of the tymp contains the lead which is tapped off by opening a tap-hole communicating with its bottom. The slags are conducted on a slope to a basin wherein they are accumulated for re-smelting.

This furnace may be fed either by charcoal or coke; the latter requires a blast somewhat stronger than the former, but in no case more than one-half or three-fourths pound pressure. A fan-blower is sufficient for charcoal; coke requires a cylinder blast. Coke operates as well as charcoal, and yields equally as much and as good metal from the ore as the latter. In working the furnace, it is warmed previously to charging ore, which is mixed with fluxes, such as litharge, iron ore, calc-spar, fluor-spar, or other substances. Fuel and ore are charged alternately, as at any other blast-furnace. The blast is generally urged in case charcoal is the fuel. The metal, or metals, gather below the tuyere in the basin of the hearth, and separate into various strata; pure lead and all the silver is at the bottom; upon this there is a stratum of alloys of lead and other metals, and on the top a stratum of matt which is covered by the poor silicious slags. The latter may be carefully drawn off and removed without drawing any matt or metal. When the matt reaches so high as to admit very little slag on its surface, the blast is stopped, the tuyere temporarily closed up, and the metal tapped into the basin. As the purest metal is below the matt, and the furnace tapped at the bottom, this flows out first; and when the drawing is not hurried, it may in some measure be separated from the impure metal and the matt on its top. Generally the metal is tapped from the furnace at intervals of eight hours, and very little is left in the furnace. When it is thus removed, the hearth is cleared of adhering cinder by opening the tymp, and the operation goes on as before. A continual blast of six days and nights work, may thus be made, after which the furnace is cooled and thoroughly repaired. In the basin before the hearth, into which the metal has been tapped, and which is kept well heated, the metals separate again into different strata, which may be obtained after removing the cold crust of slags, as it forms on the surface. As the purest lead is at the bottom of the basin, it is ladled out after the upper strata of alloy and matt have been removed. In this operation the poor slags are thrown away, and the rich ones and matt are re-smelted with the ore.

The best and purest kind of lead is smelted in a peculiarly constructed reverberatory-furnace, having strongly slopping hearths. The hearth is formed of loam, about twelve inches thick, into the surface of which a layer of finely broken slags, about four inches thick, is firmly pounded, and

cemented by heat. The basin of the hearth is about six inches deep; towards both bridges it rises considerably more. The hearth of the furnace is about twelve feet long, and eight feet wide. Wood is used as fuel. The operation in this furnace is similar to that described above, for other reverberatory furnaces. The ore is successfully sweated, roasted, and reduced. The slags which remain after that operation are reduced in the blast-furnace. In front of the furnace, as we have stated before, is a cast-iron pan, or kettle, into which the lead is tapped, and from which it is ladled into the pig-moulds. In these pans very large crystals of lead may be obtained, when the metal is suffered to cool slowly.

At the Hartz mountains, in northern Germany, galena is reduced by the assistance of iron in blast, or elbow-furnaces. When constructed for using coke, these furnaces are very low, or not more than three or four feet high; for charcoal they are from eighteen to twenty feet high. The hearth is formed of fine coal and clay. The tymp is of common brick. The interior is about two and a half feet by fifteen inches at the tuyere; the mouth (top) is fifteen inches wide and round. On the top of the furnace is a labyrinthic succession of chambers, into which the dust from the ore, or the oxides of the volatile metals are condensed. The mouth is funnel shaped to prevent the deposition of volatile metal near or below the mouth of the furnace. A hood formed at the tymp, and which communicates with the condensing chamber, draws in the vapours of those metals which escape at the tymp.

The ore which is smelted in these furnaces is always extremely well prepared, pounded, and washed. Instead of iron ore, granulated cast-iron is used with success. The ores may be very impure, but the lead is always obtained in great purity.

The reduction of lead ores is extremely simple. In all instances of smelting, a considerable loss of metal is experienced, which has been the cause of a close examination of the process, and we may assert, that no metallurgical operation is more thoroughly and scientifically known, than the reviving of lead. This metal is in most instances the bearer of silver, the bulk of which is obtained from lead ores. In order to investigate the cause of the loss in lead metal, and also a suspected loss of precious metal, much labour and ingenuity has been bestowed on this subject.

In the smelting of crude galena in a reverberatory-furnace, the sulphuret is at the commencement of the operation, deprived of a part of its sulphur by heat; metal is formed, and as oxygen finds access to the ore, oxide of lead, and consequently sulphate of lead is also formed. The proportion of these substances depends of course on the degree of care bestowed upon the process. When after two hours the roasting of the ore is so far completed as to admit of its reduction, the heat is raised so high as to form a pasty mass. Oxide of lead and sulphuret of lead now mix completely and form metal, sulphuret, and sulphate, from which mixture the metal parts by force of gravitation. In mixing carbon with the slag, the sulphate is reduced to sulphuret, which is again deprived of its sulphur by heat. Thus, by alternate oxidation and reduction of the ore, a certain amount of metal is

abstracted. The revival of lead from the slag causes it to be more refractory at the end of the operation than it was at first, because the sulphuret or the oxide of lead, which was the cause of its fusibility, is chiefly removed. When the slags are so pasty as to inclose grains of metal which have not the power of separating by gravity or cohesion, they cannot yield any metal, although the whole of it may be revived. In order to obtain all the metal from the slag, it ought to be at least as fluid as the metal itself, at the same degree of heat. Such a slag is not easily obtained without oxide of lead, or sulphurets of other metals. Salts of any kind, such as fluorides, chlorides, and sulphates, form the best auxiliaries in this operation: and if present only in a small quantity, they are of service. Lead, bismuth, antimony, and in fact all the fusible metals, will readily separate from other matter than metals, in virtue of their gravity and cohesion; but it is a necessary condition of their separation, that the matter with which these metals are combined, should be fluid. The metal cannot separate from a dry slag, an agglutination of its particles is necessary before it can subside.

A fluid cinder is necessary not only for the agglutination of the metallic particles, but also for their production. When a dry or pulverulent mixture is mixed with carbon, oxygen may be abstracted from it by the carbon; but as the newly-formed particle of metal is exposed to the influence of oxygen—which it will absorb from the products of combustion, if it cannot obtain it in another form—it will oxidize as quickly as it is reduced. If metallic oxides, or sulphurets and slags are fluid, the addition of carbon to the mixture will deprive the oxidized metal of oxygen; and if the metal as well as the slags continue to be fluid, the latter will protect the first against oxygen. The fluidity of the slags will also admit of the subsidence and gathering of the metallic particles.

In smelting galena in a reverberatory-furnace, we deprive the slags gradually of the means of fluidity by abstracting that metal from them, which has been the cause of their fusibility. This abstraction can be carried only to a certain point. When the slags cease to be fusible at the heat by which the metal melts, they must cease to furnish metal any further, however much may be contained in them. We perceive, therefore, very readily, that the quantity of metal retained by the slag depends entirely on its fusibility, and not on its composition. Lead, like the precious metals, separates easily from all other matter, and thus far the composition of the slags has little effect on its quality. If, in operating on galena, fluxes can be introduced which continue the fluidity of the slags at a moderate heat, all the lead, even the last particle of it may be obtained.

The fluidity of slags depends as well on heat as on their composition; we may continue the fluidity of a slag by increasing the heat; this, however applicable with some metals, is not the fact with lead. When the heat on metals is raised beyond a certain degree, they evaporate. In any smelting operation therefore, it should not exceed that degree. Metallic lead, and especially oxide of lead, sulphuret and salts of lead, are very volatile, and a strong heat on them must be avoided. It must be, therefore, the practice to

smelt lead by as low a heat as possible; and in order to accomplish this, a mixture of ore must be prepared which affords a fusible slag without lead.

Lead combines very readily with other substances under certain conditions, and in most instances in definite proportions. Iron will combine with sulphur in all proportions, but not so lead. There are various combinations of lead and sulphur, which, when exposed to heat, form the combination which we recognize in galena. If less sulphur is present, metal and sulphuret are formed. This accounts for the revival of pure lead from galena that is partially roasted. In the composition of reverberatory and blast-furnace slags, we find the means of detecting the true conditions under which lead is smelted most profitably.

A slag which had been deprived of its metal by a long continued operation in the reverberatory—sixteen hours' work—contained still 13 per cent. of oxide of lead, 58·5 oxide of iron, 11·5 barytas, and 5 sulphuret of lead; also 17 silex. This shows that the last particles of sulphur will adhere to lead, when all other substances are oxidized. A reverberatory slag entirely free from sulphur, contained 51 sulphate of barytas, 10·5 sulphate of lime, 1·5 fluoric acid, 3 protoxide of iron, and 34 oxide of lead. A slag obtained from impure galena, that is, an ore from which heavy spar could not be separated, was composed of 30 sulphate of lead, 24 sulphate of barytas, 5·6 gypsum, 8·5 fluoric acid, 14·7 carbonate of lime, 2 sulphuret of lead, 5·6 protoxide of iron, 8 oxide of zinc. A very fluid slag which flowed off with the metal, contained 9 sulphate of lead, 30 sulphate of barytas, 33 sulphate of lime, 13·6 fluoric acid, 8·8 lime, 2 oxide of iron, and 2 oxide of zinc. This contains the least lead, and large quantities of alkaline salts; all the alkaline earths are combined with some acid, which renders the compound fluid.

The last-mentioned slag is produced from crude galena, which has been merely freed by hand from impurities, and for these reasons we invite attention to it. It shows a very rational operation. The ore is charged in the furnace in the common manner, and reduced so far as it will furnish metal. When the slag becomes too stiff for yielding metal, some finely-pulverized fluate of lime is thrown in and mixed with the mass. This renders the barytas and gypsum fusible, and the reduction of galena may take place. So long as the fluidity of the slag is continued, lead is formed. To render this operation profitable, fluate of lime should be used in a considerable quantity; but as this cannot be obtained always, we propose the substitution of the chlorine for fluorine, which possesses in as high a degree as the latter, the quality of fluxing sulphates. In this instance, gypsum and common salt may be pulverized together when damp. These form a very fluid slag with barytas, lime, iron, and other metals.

The following reverberatory slags shows that lead can be removed almost entirely from the ore, in oxidizing the mixture completely. A slag from zinc ore contained 64·5 protoxide of iron, 2·5 oxide of lead, 1 oxide of zinc, 2·5 alumina, and 29·5 silex. The iron and silex here form the slag. It must be observed that in precipitating all the lead from a slag by means of iron, the

metal will contain much iron and be otherwise impure. When an ore contains much zinc there is hardly any other profitable way of smelting it, than to flux by means of iron, either with iron ore or pyrites; all or most of the zinc, remains then in the slag.

The slags of blast-furnaces differ somewhat from those of the reverberatory, in containing more silex, and in most cases, less lead. A slag which was formed at a moderate heat, and considered as exhausted of lead, contained 34·4 oxide of iron, 6·6 oxide of lead, 7 lime, 9 sulphuret of iron, a little manganese and oxide of zinc, and 34·8 silex. A slag from an argentiferous galena, contained 45·4 protoxide of iron, 11·2 magnesia, 2 sulphuret of iron, 3·9 alumina, and 36·3 silex. The following proportions show that a large quantity of lime is of no advantage; 25 protoxide of iron, 24 lime, 10·6 zinc, 3 oxide of lead, 7 alumina, 28·5 silex. The following is a profitable slag: 34·8 protoxide of iron, 6·8 oxide of zinc, 2·4 oxide of copper, 7 manganese, 6·6 lime, ·6 magnesia, 2 oxide of lead, 12 sulphuret of iron, and 3·4 alumina.

When ores are exposed to a low heat, they hardly enter into any combination with silex, and of these the oxides only. Sulphurets, sulphates, chlorides, fluorides, and, in fact, all other metallic compounds, do not combine with silex; it is only after all other matter is evaporated, that the oxides unite with that acid. We may smelt lead to perfection without forming any silicate; but this requires the presence of a large quantity of chlorine, fluorine, or some other permanent acid. In roasting the ores before smelting, we are deprived of the advantages resulting from the fusibility of the sulphurets and acids, and are compelled to form silicates, because those substances which form a fluid slag in the low heat of a reverberatory-furnace, evaporate in the heat of a blast-furnace and are lost. When it is in our power to form a fusible slag, either by means of fluates or chlorides and sulphates, it is more profitable to smelt in a reverberatory than in a blast-furnace, and precipitate the lead to within a few per cent., in the first and only operation. In this instance the ore needs no crushing and expensive washing, a removal of the coarsest pieces of quartz, and of the loam, is the only labour necessary to be performed on it. The presence of quartz will not influence the result, because when other acids are present, it does not enter into combination. If no materials are at hand to form a fusible slag, either by natural or artificial means, then it is necessary to roast the ore and smelt in the blast-furnace. In this instance, the ores must be roasted, because the sulphurets are very volatile, and will not resist the heat of that furnace. The most profitable flux is the protoxide of iron. Lime or magnesia, and other alkaline earths, do not form sufficiently fluid slags to used profitably.

When circumstances render it necessary to smelt in blast-furnaces, the operation ought to be conducted in such a manner as to obtain all the lead at one smelting. This appears sometimes to be difficult, but it is not so where cheap iron ore can be obtained in sufficient quantity. When a slag or ore is to be exposed to smelting in a blast-furnace, it ought to be thoroughly oxidized; because if any sulphur is left in it, even in the form of

sulphate, lead, and zinc, are the first to evaporate. Lime does not remove sulphur, but combines with it, like all other alkalies. Iron, because it absorbs sulphur, and as easily parts with it, is the most suitable substance to mix with the sulphureous ore for the purpose of oxidation; it forms a fluid slag at quite a low heat with silex, and is thus far the best flux in the blast-furnace. Manganese serves equally as well as iron, and may be substituted for it; but no other metallic oxide can be substituted for these two.

When sulphurets of lead are roasted in the air, they are never entirely liberated from sulphur; the most carefully roasted lead ore contains sulphur. Galena roasted with extreme care, in a heap, contained 18 oxide of lead, 86 sulphate of lead, and 10 sulphuret of lead. The same galena roasted during seven hours in a reverberatory, formed metallic lead, and the roasted ore powder consisted of 30 oxide of lead, 46 sulphuret of lead, 17 metallic lead, and 7 iron oxide and silex. When other metals are present besides lead, such as iron, zinc, and others, they are oxidized before all the sulphur is removed. A persevering roasting of ten or twelve hours in a reverberatory-furnace, will remove much of the sulphur; but from eight to ten per cent. of sulphate of lead remains in all instances. The presence of a large quantity of silex, say twenty-five per cent. of the ore, is the best means for the removal of sulphur. From such ore the last trace of sulphur may be removed in the reverberatory-furnace, or in roasting it in the open air. It would not make any difference by what means sulphur is removed in roasting, and silex might serve quite as well as iron, if it could be removed advantageously before bringing the ore or slag into the blast-furnace.

In practice at the furnaces, we find the above principles operate under forms modified by local circumstances. The smelters at a reverberatory-furnace alternately cool and heat the furnace, in order to oxidize and reduce by means of granulated coal. A fluid slag cannot quickly oxidize; it is like melted metal in this respect; there are no points of contact for the oxygen. The drying up of the slags, by cold or drying flux, such as lime, facilitates the oxidation of the sulphuret. The best plan is to run the metal and slags out continually, the first into a heated iron pan, the latter over damp charcoal-dust. This mode of operation causes oxidation quicker than any other. When the slag is cooled, it may be recharged or reserved for the slag-furnace. Slack coal should never be mixed with the slag for reduction; a granulated coal assists in forming large globules of metal; it affords points of oxidation for the slag, and does not stiffen it so much as find coal. When litharge is reduced in a reverberatory, it does not work well if both coal and litharge are fine; this is not from want of affinity or other secret causes. The powdered mass does not admit of the formation of a large globule of metal, or of motion in the fluid metal, which is necessary for agglutination. And as oxide of lead, particularly when mixed with a refractory substance, does not melt at so low a heat as metallic lead, the whole must be heated until the mixture of oxide and coal begins to become fluid, and admits of the subsidence of the metal. Litharge is easily reduced in the reverberatory-furnace. A charge, consisting of one ton of litharge, may be smelted in one and a half

or two hours, when in a granulated form; but when finely ground litharge or fine coal is used, twice as much time is required. When the heat must be urged so high as to melt the litharge, the process is slow. We find the principle of the operation here to be different from that of smelting ore; if, in the latter case, we work the ore dry, as litharge, we produce but little metal. The cause of this is plain; there are impurities and metal in close contact in the ore, and no large globule of metal can be formed, because the foreign matter interposes between the particles of metal.

The conditions under which successful smelting may be performed, are therefore very plain. A fluid slag is in all cases required where impure ore is to be smelted; pure ore or litharge, may be worked more dry than impure ore. Fusible slag may be produced by a variety of means, of which heat is the most available, but not the most profitable. High heat causes a loss of metal by evaporation; it brings foreign metals into the lead, which are injurious to its quality. Lead, and in fact all other metals, ought to be smelted at the lowest heat by which they can be melted. A low heat will produce the best metal in all instances, and as that kind of work demands less fuel and labour, too much attention cannot be bestowed no this subject. Fusible slag should be formed by means of fluxes, not by heat, which will, in most instances, remove those ingredients which cause fluidity. Protoxide of iron, which is most successfully formed of powdered hematite-ore and carbon, forms readily a fusible slag, in the presence of chlorine, fluorine, sulphuric, phosphoric, or any other acid; but these acids are soon evaporated by a strong heat.

Smelters dislike the use of much iron in a reverberatory, as well as in the blast-furnace, because in its most fluid condition, it acts upon the stones, bricks, and slags, of which the hearth is formed, and causes their premature destruction. When the work is done on a fine charcoal or coke hearth, in the presence of much iron, it is reduced with the lead, and impairs its quality. We recommend for these reasons, for smelting lead, the application of cooled boshes, and cold cast-iron bottoms, such as are used in puddling-furnaces. In the slag-hearth and blast-furnace, iron plates are generally used below the tuyere, and are lined with clay or coal-dust; but both these materials for linings are injurious as well to the quality of the metal as to the yield. There cannot be any disadvantage in surrounding a slag-hearth with cooled iron plates, similar to a run-out fire for refining iron. A little more fuel may be used in smelting, but a more fluid cinder can then be employed than in any furnace, which of course tends to economize fuel; and causes a purer article of metal. Furnaces of this kind were used in the State of New York, and worked successfully. The hearth-plates were cooled by the blast.

At the smelting-furnaces, particularly at those where the operation is performed at a high heat, a white smoke is thrown out at the tymp, or at the top of the furnace; this may be gathered in condensing chambers. Similar chambers may be annexed to reverberatory-furnace. This white smoke contains those metals which are in the ore. A reddish dust from a

reverberatory-furnace contained, 11 oxide of lead, 60 sulphate of lead, 2 arsenious acid, 15 oxide of zinc, 12 oxide of iron. When there is much zinc in the ore, and it of course evaporates, a large quantity of silver is carried away by it. Iron and coal are generally the colouring matters in the body of these deposits. It is always found to be chiefly oxide and sulphate of lead.

Chemical Summary.—The minerals from which metals are extracted, consist in most instances, of chemical compounds of the metal with various other substances; consequently, the process by means of which the metals are extracted from their ores, are, generally speaking, chemical, and consist in the decomposition of the compounds constituting the ores, together with the production of other compounds in which the substance to be separated, does not constitute a part. One of the essential conditions of this chemical change is that one or both of the substances should be in the liquid or gaseous state.

Metallic ores might, therefore, be decomposed by being subjected to the action of certain gasses or liquids, and in some cases this is done; but the general practice is to transform the ore itself into the liquid state by fusion. In both cases a temperature approaching redness is necessary for the production of the desired change, and consequently this method of operating is technically called the "dry way," *vocé séche*, *trocknen wege*, while the treatment of ores with aqueous liquids is called the "wet way." There is, however, scarcely any essential difference between the processes set up in both methods of operation, for in both cases it is heat which determines the mobility of the particles of a gas or a liquid, the only difference being that some substances are liquid or gaseous at the ordinary atmospheric temperature, while others acquire this state only at more elevated temperatures. Nevertheless, there is a practical advantage in classing metallurgical operations under the two heads of the dry and wet methods.

The nature of the operations by which metals are extracted from their ores, depends upon the chemical nature of the metal to be extracted.

The metallic ores which are most frequent and abundant, have generally the following composition:—

1. *Oxides.*—This is the most frequent state in which metals occur.

2. *Sulphides.*—This is the general composition of ores of copper, lead, antimony, and in part of silver and zinc. These ores bear the names of pyrites, glance, or blende.

3. *Arsenides* constitute but an unimportant part of metallic ores.

4. *Metallic salts;* the most frequent being carbonates, including the spathic ores of iron, zinc, lead, and copper; but as these compounds may be deprived of their carbonic acid by ignition, their metallurgical treatment coincides with that of the oxides. Other metallic salts, such as sulphates, phosphates, arsenates, and silicates, are only of rare occurrance as ores.

These minerals do not occur in a state of purity to such an extent as is requisite for the extraction of the metals. Most ores are rather associated with ores of other metals, from which they cannot be separated by mechanical means, as for instance, copper pyrites, galena, or blende; or they contain

several metals; for instance, copper and lead in bournonite, lead and silver in galena. Hence it follows that in the first instance, ores, when melted frequently yield products which require to be subjected to special operations for the separation of the metals they contain.

A still more important circumstance, is the association of metallic ores with minerals that do not contain metals, and which constitute the matrix in which the ore is imbedded. These admixtures can rarely be separated mechanically, and indeed are sometimes very serviceable in the smelting operation.

Smelting.—While the chemical changes which ores and metallurgical products undergo in roasting, are effected by the action of certain gases upon the solid compounds of the metal; the chemical processes that take place in smelting operations, consist in the reaction of the ore with other substances while in a liquid state. The object of the smelting operation, is always to effect, or approach near to the separation of the substances combined or mixed with the metal, and to obtain this in a state of regulus. The mere chemical elimination of the metal would be of little service in practical metallurgy, unless it were effected under such conditions as would admit of its mechanical separation from the other products of the operation. In all smelting operations, there is such a mechanical separation of two or more substances in layers, one above the other. The composition of these several layers, will at once be evident from the composition of the materials operated upon. As a general rule, these will contain certain admitxures, consisting in part, of silicates of the earths and alkalies; in part also, of quartz, limestone, &c. These substances are generally infusible, or fusible only at very high temperatures, so that it is necessary to convert them into a state in which they may be smelted. This is effected by fusing with the ore other substances, which will combine with those that are to be separated, and in the fusion, give rise to the production of a vitreous mass called *slag*. Even when the ore consists entirely of a metallic oxide, it is always advisable in practice to mix it, according to its nature, other substances which contribute to the production of slag, because by this means the fusion is facilitated, and the surface of the reduced metal is protected by the slag from the oxidizing action of the air passing through the surface.

The slags produced in metallurgical operations are essentially compounds of silica with earths, chiefly lime, magnesia, and alumina, or with metallic oxides, such as protoxides of iron, or of manganese. They also contain in some instances, alkalies, baryta, oxides of zinc, copper, or lead, small amounts of fluorine and sulphur compounds, phosphates, and sulphates, and sometimes granules of reduced metal, or other products of the smelting operation.

These compounds belong to the class of oxygen salts, and are analogous to the siliceous minerals which constitute rocks. The silica in these substances is a compound of silicum with three equivalents of oxygen ($Si\,O^3$), and has the functions of an acid. At high temperatures silica displaces all acids that are volatilizable, and unite with the bases they were combined

with. It also combines with most bases in several different proportions; those silicates being regarded as neutral salts, in which the proportion of oxygen in the base is to that in the acid, as 1 : 3; and those silicates in which the proportions are different from this, being called acid or basic according to the preponderance of silica or of base.

Oxygen Ratio in base		in acid.		General Formulæ of Silicates.	
1	:	3	neutral silicate	$RO\ SiO^3$ or $R^2O^3\ 3SiO^3$	*a*
1	:	2	basic silicates	$3RO,2SiO^2$ or $R^2O^3,2SiO^3$	*b*
1	:	$1\frac{1}{2}$	basic silicates	$2RO,\ SiO^3$ or $R^2O^3,3SiO^3$	*c*
1	:	1	basic silicates	$(3RO)\ SiO^3$ or $R^2O^3,\ SiO^3$	*d*

Since the fusibility of slag is a character of great importance in reference to the smelting of ores; and since this character is partly determined by the nature of the bases, and partly by the proportion in which it is combined with the silica, it is desirable that the metallurgist should be acquainted with the fusibility of the various silicates of those bases which are usually present in metallic ores.

The investigations that have been made in reference to this point, show that among the calcareous silicates, that which is represented by the symbolic formula $3CaO,\ 2SiO^3$, is the most fusible; the neutral silicate $CaO,\ SiO^3$ is less fusible, and the others are almost infusible. The amount of lime in the fusible silicate of lime, varies from twenty-five to forty-seven per cent.

The magnesian silicates are fusible only at very high temperatures, and those corresponding with the above formulæ, are at the most, only softened.

Aluminous silicates are probably quite infusible.

All double silicates are more fusible than the simple silicates, and any infusible silicate may be dissolved by some other silicate in a melted state. Thus, for instance, the substances represented by the symbolic formulæ $3CaO,\ 2SiO^3 + 3MgO,\ 2SiO^3$, $(3CaO),\ Si^3 + Al^2O^3SiO^3$, are both tolerably fusible, and even the corresponding compound of magnesian and aluminous silicates may be melted.

The compounds of silica with the protoxides of iron and manganese, corresponding with the formulæ *a* and *b*, are very fusible substances, but the compounds of silica with peroxide of iron are stated to be infusible.

Plattner has estimated the melting point of some slags as follows;—

Slag from iron smelting in shaft-furuace	$3CaO,\ 2SiO^3 + Al^2O^3SiO^3$ containing three per cent. protoxide of iron	2608° Fah.
Slag from iron smelting in shaft-furnace	$(CaO,\ MgO)\ (SiO^3Al^2O^3)$ $Mg : Ca = 2 : 3\ \ Al : Si = 1 : 5$	2433° Fah.
Slag from lead smelting	$3[3RO,\ SiO^3] + Al^2O^3\ 2SiO^3$ containing lime, magnesia, protoxide of iron, and 1·5 per cent. oxide of lead	2403° Fah.
Slag from copper smelting	$4[3FeO,\ SiO^3 + Al^2O^3\ SiO^3]$	2440° Fah.

The following melting points of metals will serve for comparison :—

Silver . .	1873° Fah.
Gold . . .	2015° Fah.
Copper . .	2143° Fah.
Platinum . .	4593° Fah.

The mode of solidification is another important character of slags. The slags consisting chiefly of silicates, corresponding with the general formula *d*, are very liquid when melted, and solidify rapidly; those corresponding with the formulæ *a* and *b* are viscous when melted, and solidify much more slowly.

Although slags are in all instances to be symboled as chemical compounds of silica with bases, it is, nevertheless, possible that a slag may consist of a mixture of several distinct silicates, since both the simple and double silicates are miscible in all proportions when melted, and since the cooling of the slag takes place too rapidly to admit of a separation of the different silicates which it may contain this is in fact the most frequent case, slags consisting as a whole of a distinct chemical compound, being of rare occurrence. It is only the slags which contain but one base, such as the ferruginous slags, consisting of protoxide of iron which consists entirely of one silicate, and even these are sometimes mixed with other substances; thus, for instance, the slag obtained in refining iron, is a mixture of silicate of iron $(3FeO)SiO^3$ with oxide of iron FeO, Fe^2O^3 in variable proportions.

Slags are either vitreous or stony, and in the latter case they are not unfrequently more or less crystalline.

The amorphous slags in their most perfect state, appear as true glasses, and are transparent when they do not contain metallic oxides in large amount. Their fracture is conchoidal, and the structure the same in all directions. This class of slags comprises many that must be regarded as mixtures, and for that reason have not a crystalline structure. But all vitreous slags are not of this kind, this peculiarity of structure being sometimes the result of rapid cooling.

The stony slags are likewise either mixtures or definite compounds. It is the latter kind only, that are crystalline.

Every well conducted melting operation involves the production of a slag possessing a certain constant composition and uniform degree of fusibility; and any development of the requisite conditions becomes evident in the production of abnormal slags. When the chemical nature of the ore is known, it is generally easy to prepare the charge, so as to answer the success of the operation by a due regard to the general principles already stated in reference to the fusibility of the silicates.

The object of the most important melting operations in metallurgy, being to effect the reduction of a particular metallic oxide at the lowest possible temperature; and at the same time, the separation of the substances mixed with the ore, by converting them into a fusible slag. The degree of fusibility requisite for the slags, will therefore depend upon the temperature at which the oxide is reduced; the lower the temperature the more fusible must the slag be. Hence one of the most important conditions to be secured is, that the charge may contain such substances as will contribute to the production of slag, and in such proportions that the slag will have the proper degree of fusibility. At the same time, the slag must never be so fusible as to melt at a lower temperature than that at which the oxide is reduced, for in that

case a portion of the oxide would be dissolved by the slag, involving a corresponding loss of metal.

Imperfectly melted slags always present a kind of granular fracture, and are produced when the charge is not properly prepared, when either silica or lime preponderate, or when the amount of alumina or magnesia is very large. They may also be produced when the quantity of fuel is too small in proportion to that of the charge, and when consequently the temperature produced, is not sufficiently high to effect the proper fusion. When the proportion of base is too small, there may be a loss of metal, owing to the oxide being dissolved by the slag, and taking the place of the deficient base.

The ore sometimes contains metallic sulphides, which collect in a homogenous mass called "metal" or matte, and in other cases slag, metal and regulus are produced together. The slag always forms the upper layer, the regulus is always at the bottom, and the metal between the two. Sometimes a fourth layer is produced, containing a large amount of arsenic or antimony, and called "speiss."

The melting operation is generally conducted in a shaft-furnace or reverberatory-furnace; in the former, the charge is in direct contact with the fuel; in the latter, it is acted upon only by the heated gases produced by combustion.

In most melting operations the chief chemical process consist in the abstraction of oxygen from some oxide or oxidized compound of a metal, or as it is technically termed, the reduction of the metalliferous substance. The reducing substances usually employed, are carbon in the state of coal, charcoal, &c; also carbonic oxide, carbonetted hydrogen and hydrogen, which are generated by the partial combustion of the fuel, and by the action of heat upon it. At high temperatures carbon abstracts oxygen from all metallic oxides iliminating the metal and producing carbonic oxide. Metallic oxides differ considerably in this respect, some being reduced with great ease at low temperatures, even without the aid of carbon or any other substance to combine with the oxygen; others, again, require to be subjected to the action of the most intense heat, and the most powerful reducing agents.

The mode in which the reduction takes place, is not in all cases the same; when the oxygenous substance is readily fusible, there is an intimate contact between it and the coal, as in the reduction of oxide of lead or of bismuth; but when that substance is not fusible, the contact is slight, even when it and the coal are finely powdered, and the reduction would be only partial if another favourable circumstance did not determine the contrary. The oxygen of the atmospheric air filling the interstices of the mass, combines with the carbon present in excess, producing carbonic oxide, which coming in contact with the oxygenous ore, effects its reduction, and by abstracting its oxygen, is converted into carbonic acid. For the production of the carbonic oxide requisite for the complete reduction of the ore, it is not essential that there should be a continued supply of fresh atmospheric air, because the carbonic acid in contact with red hot fuel, is again converted

into carbonic oxide, which reduces a fresh portion of oxide, and thus serves to abstract the oxygen from the whole of the ore.

In this way the reduction of metallic oxides which are not easily melted, may be effected in closed vessels by means of coal. It is not until after the reduction has been effected, that the fusion of the metal takes place.

It has already been remarked that ores contain various admixtures, which are either basic—like the earths, or acid—like silica, in their chemical relations, and consequently the substances to be added to an ore in preparing the charge for the melting operation, will depend upon the nature of these admixtures. Thus, siliceous ores require an addition of base; calcarious ores an addition of silica, &c. The substances that are most generally used for this purpose are silica, in the state of quartz, sand, &c.; carbonate of lime in the state of limestone, or dolomite, fluor spar, or slags from previous operations.

Slags are employed in melting operations, chiefly on account of their solvent action upon certain metallic oxides. The kind of slag to be used will depend upon the nature of the substance to be separated in the fusion. It is chiefly for the purpose of separating the oxides of iron produced in the roasting of certain ores, from other metallic oxides with which they are associated, that the solvent action of slags is taken advantage of in metallurgical operations. Thus, for instance, when a mixture of peroxide of iron, suboxide of copper, and a slag corresponding with the formula *b* or *d*, is melted under conditions that effect reduction; the peroxide of iron will be reduced to protoxide, and then dissolved by the slag, while the reduced copper will collect as a regulus under this slag. In similar cases all oxides that are not easily reduced, will behave like peroxide of iron, and those that are readily reduced will behave like oxide of copper. It may indeed be regarded as a general rule that when a mixture of oxides that are unequally reducible, with a slag containing a certain amount of silica, is melted under circumstances that determine reduction, the less reducible oxides are dissolved by the slag, while the more reducible oxides are deprived of their oxygen entirely, and the metal obtained, a regular proportion of this result requires that the slag should be present in a certain production, and that its melting point should be between that of the different oxides. When there is not sufficient slag to dissolve the whole of the protoxide of iron, a portion would be reduced to metal, and the slag was fusible at a temperature lower than that at which the suboxide of copper is reduced, a portion of this oxide would be dissolved by the slag and its reduction prevented, while if the protoxide of iron was reduced at a temperature lower than that at which the slag melted, the regulus would contain a considerable amount of iron.

Metallic lead is sometimes employed as a solvent in a similar manner. When this metal is melted with auriferous or argentiferous sulphides; it dissolves the gold or silver, sulphide of lead being produced, and gold or silver is eliminated, while there is scarcely any reaction of a similar kind between metallic lead and the sulphides of iron or of copper. By this means, therefore, auriferous or argentiferous lead is obtained as the product of the

fusion, together with a matte of sulphide of iron, or of copper, which on account of the inferior density of these substances, collects upon the top of the lead.

Some sulphides also serve for the extraction of gold or silver from melted ores, thus for instance, sulphide of iron, iron pyrites, or magnetic pyrites, that contained only a small amount of silver, and which when melted alone, would yield slags that contained a very considerable proportion of the silver, dissolves almost the whole of the silver as sulphide.

There is another purpose which metals serve in some melting operations; this is the decomposition of sulphides, and the elimination of one metal, by another metal whose sulphide is more stable under the circumstances. Thus when sulphide of lead is melted with metallic iron, the sulphur is transferred from the lead to the iron, and the lead is obtained as a regulus. Iron is the only metal which is used for this purpose in metallurgy; consequently the relation of iron to sulphides is especially of practical interest.

The results of Fournets's experiments on the reaction between sulphides and metals, may be generally expressed as follows:—

Of the sulphides of copper, iron, tin, zinc, lead, silver, antimony, and arsenic. Sulphide of copper is most stable, and sulphide of arsenic the least so; the other members of the series differing in this respect, according to their position. Any two of the metals which are next to each other in this series, do not abstract from the sulphide of one of them the whole of the sulphur; but the abstraction of sulphur from the sulphides of this metal, is effected most completely by this more remote proceeding member of the series.

The metals of the alkalies and alkaline earths, are the most effectual in abstracting sulphur from metallic sulphides. The influence of the metals is exercised when their oxides are ignited together with carbon in some state, and a metallic sulphide. By this means the alkaline metal is eliminated by the carbon, and thus exercises its desulphurizing action upon the metallic sulphide, giving rise to the production of a regulus and an alkaline sulphide. Very frequently the whole of the metallic sulphide is not decomposed, a portion of it being dissolved by the alkaline sulphide produced. When the melting is made without coals, a regulus is still obtained, and at the same time a metallic sulphate of oxide is produced by the action of the oxygen of the alkali upon the metallic sulphide. At the same time a considerable portion of the metallic sulphide is dissolved. When an alkaline or earthy carbonate is used, the decomposition is still less complete. Thus sulphide of copper melted with carbonate of potash is not all decomposed, but when melted with caustic potash it is decomposed. However, when carbon is added, the same effect is produced with the carbonates as with the caustic alkalies or earths.

Oxidation is another feature of the melting operation, which is frequently important in metallurgical practice, inasmuch as it is a means by which substances that are readily oxidized, may be separated from others which are less readily oxidized, more especially when the former are in the state of

oxide, either volatile, fusible, or dissolved by the ordinary fluxes. The most general oxidizing agent is atmospheric air; but sometimes substances are used which, like oxide of lead, sulphates of copper, or of iron, nitre, and basic silicate of protoxide of iron, yield oxygen at high temperatures.

Thus, for instance, when a current of air is passed over the surface of melted copper containing iron, cobalt, lead, antimony, arsenic, and sulphur, the last three substances are volatilized as oxides, while a more or less liquid layer collects upon the surface of the copper, consisting of oxide of iron, protoxide of cobalt, oxide of lead, antimonous acid, and suboxide of copper, and the greater portion of the copper remains as almost pure metal. The larger the proportion of lead as compared with the other metals to be separated, the greater will be the fusibility of the mixture of oxides, and when the proportion is small, some means must be devised of removing it, so that a fresh metallic surface may be exposed to the oxidizing action of the air. This takes place when the mixture of oxides are liquid, and the quality is not very considerable, partly in consequence of the convexity of the surface of the melted metal, and partly by the mechanical action of the blast.

The results obtained by Berthier, in reference to the reaction of metallic oxides upon different metals may be generally expressed as follows;—

When one of the more readily oxidable metals is melted with the oxide of another metal, there is always an oxidation, at least partial, of the former, and the proportion of oxide produced, is determined partly by the relative amount of the oxide employed, and partly by the degree in which the metal is electro-positive to the oxide, or the oxide electro-negative to the metal.

The reaction between oxide of lead and metallic sulphides when melted together, is of especial importance in metallurgy. When the sulphides of iron, or of copper, or copper pyrites, are melted with a sufficient proportion of oxide of lead, the whole of the sulphur is volatilized as sulphurous acid, and the iron or copper is oxidized, the iron probably as $FeO\ Fe^2O^3$, the copper Ca^2O, while the oxide of lead that is not decomposed, forms, together with the oxide of iron or copper, a vitreous slag, which collects on the top of the metallic lead. When the oxide of lead amounts to less than twenty times the weight of the copper pyrites, the sulphide of copper is not wholly decomposed; and the portion that remains is not dissolved by the slag consisting of oxides of lead and oxides of iron, but forms together with a part of the metallic lead a matte.

Carbonate of lead acts in the same manner as oxide of lead, into which it is converted by loss of carbonic acid.

Silicate of lead acts in a similar manner, but a much larger proportion, and a higher temperature are required. The slags produced consist, in these cases, of double silicates of lead and the oxide of the metal worked. Sulphate of lead is a much more effective oxidizing agent than oxide of lead, inasmuch as the sulphuric acid it contains, contributes oxygen to its conversion into sulphurous acid. Thus sulphate of lead melted with sulphide of lead in certain proportions, yield only lead and sulphurous acid. Protosulphate of

iron and sulphate of copper exercise a similar deoxidizing action when melted together with sulphides.

The nitrates of potash and soda, although powerful oxidizing agents, are both too costly to be used except in some few metallurgical operations.

Basic silicate of protoxide of iron [6FeO] SiO^3 is an oxidizing agent which is employed in one of the most important metallurgical operations,—the refining of iron. The theory of this operation is the following:—When iron containing carbon, silicum, sulphur and other substances that are more oxidable than iron, is melted with this basic silicate of iron, or heated with it so strongly that the iron softens and the silicate melts, one half of the protoxide of iron contained in the latter is decomposed into iron and oxygen, which combines with the above named substances, the removal of which from the iron is the object of the refining operation. In this way the carbon is converted into carbonic oxide, the silicum into silica, and the sulphur into sulphurous acid, while the silicate is converted from (6FeO) SiO^3 into (3FeO) SiO^3.

The examples already given will suffice to show that the chemical processes which take place in the melting operations, are of very different and even opposite natures. From a practical point of view, however, that particular reaction, which is most immediately connected with the result sought to be attained, is alone refered to in speaking of the operation, although reduction is always accompanied with oxidation, and the reverse.

In different melting operations, two or more of these processes may take place simultaneously; thus, for example, when a mixture of suboxide of copper, oxide of iron, and slag containing excess of silica, is melted under conditions which determine reduction, the oxide of copper is reduced, and copper eliminated as regulus, the oxide of iron is reduced to protoxide, which is dissolved by the slag, so that this melting operation is both reducing and solvent.

Again, when ore consisting of sulphide of lead, gangue, or earthy substances, is melted with oxide of iron and a suitable slag, the action that takes place, consists in the solution of the gangue or earthy substances by the melted slag; the reduction of oxide of iron to protoxide, which reacts upon the sulphide of lead, oxidising a portion of its sulphur, which is volatilized as sulphurous acid; while the iron thereby eliminated, abstracts the remaining portion of sulphur, and precipitates the lead as regulus. In this case, the reaction comprises all the important features of the melting operation.

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